PASSIVE SOLAR IN THE CITY:
An Energy Conscious Design for a
Subsidized Multi-family Housing Development

by Karen M. Duncan
B.A. Arch., Stanford University, Stanford 1978

Submitted in partial fulfillment of the requirements
for the Degree of Master of Architecture at the
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Signature of Author_____
Department of Architecture
May 8, 1981

Certified by_____
Timothy E. Johnson
Principal Research Associate
Thesis Supervisor

Accepted by_____
Professor Sandra Howell, Chairman
Departmental Committee for Graduate Students

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ABSTRACT

Until now, passive solar energy has been overlooked as a viable alternative for home heating in urban subsidized housing. Rather ironically, in housing whose residents could most benefit from the use of solar energy, such concepts and technologies are not utilized.

This thesis demonstrates how passive solar heating and energy conscious design can be economically implemented in low- and moderate-income subsidized housing. The research and design work presented explain the well-integrated system of natural environmental tempering that includes passive solar heating, natural daylighting, natural ventilation and energy conservation. A crucial aspect of the thesis is the method of dollar-for-dollar tradeoffs that is used to keep the cost of the natural environmental tempering components within the strict budget constraints of subsidized housing.

Also, the housing is designed with careful attention paid to the needs of the inhabitants. Thus, in addition to the energy concerns, the design reflects new attitudes toward sudsidized housing. The resulting solar architecture is a significant answer to the need for economical public housing that allows low-income urban residents to benefit from the sun's abundant energy.

Thesis Supervisor: Timothy E. Johnson
Title: Principal Research Associate

ACKNOWLEDGEMENTS

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Most of all I wish to thank my family whose abundant love and encouragement have been my source of strength throughout my life. My love and appreciation for them is immeasurable.

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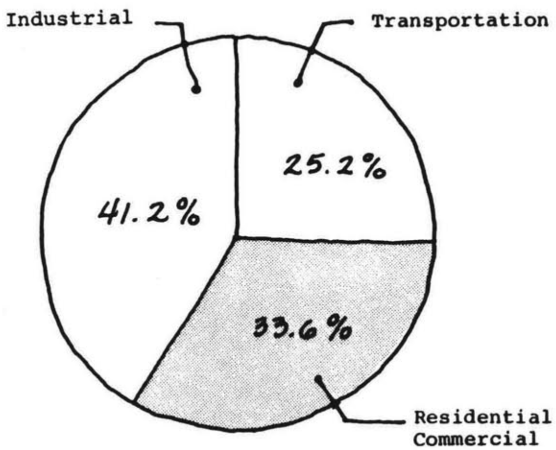
INTRODUCTION

Introduction

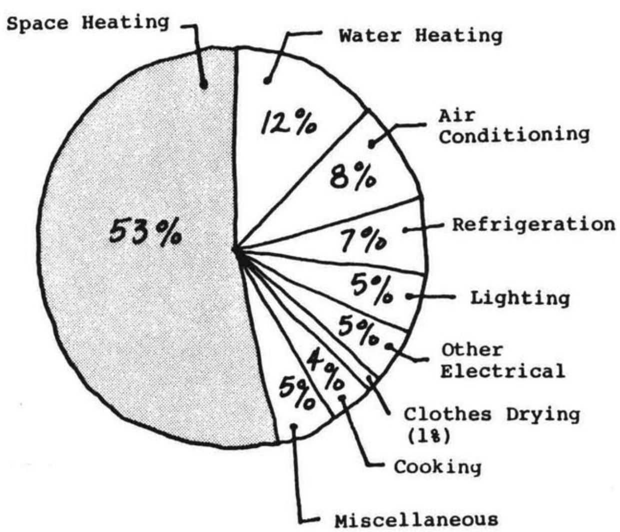
A prime opportunity for lowering operating costs continues to be overlooked in urban public housing. Rather ironically, in housing whose residents could most benefit from the use of alternative energy sources, solar concepts and techniques are not even considered. The expansion of the suburbs and the rapid growth of single family development in the 1950's excluded the less affluent. In the same way, development of alternative energy sources in the 1970's and 80's is focused on the well-to-do in suburban single family homes.

The hypothesis guiding this research and design work is that passive solar heating and energy conscious design can benefit low and moderate income people living in subsidized housing; and this can be done within the strict budget constraints of subsidized housing. Thus, the advantages of alternative energy use may be reaped by all.

At the same time, this housing must be sensitively designed with careful attention paid to the needs of the inhabitants. Historically, public housing has provided less than



Total U.S. Energy Use



Commercial/Residential Use Breakdown

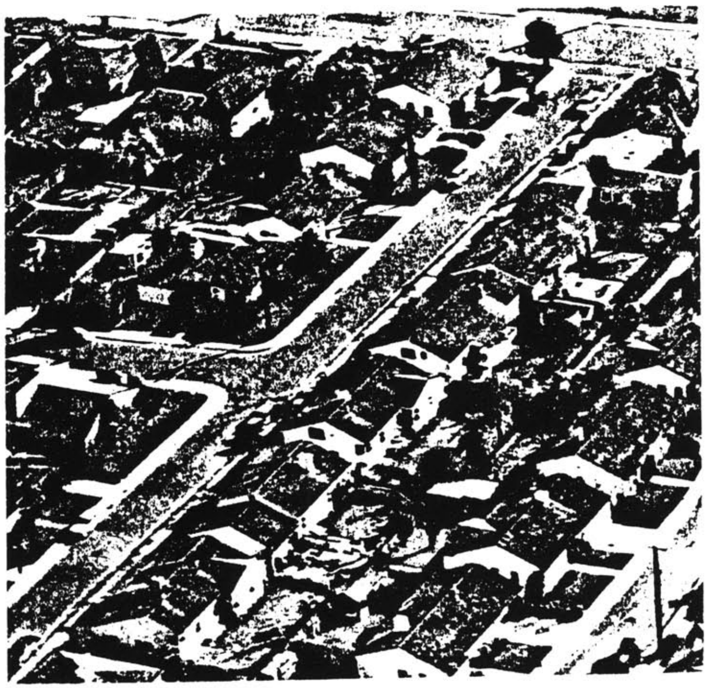
Source: Solar Cooling and Heating, 1978, p.66.

satisfactory living environments for the nation's poor. Therefore, in addition to energy concerns, the design reflects new attitudes toward public housing. Through this design solution, it is shown that these two concerns can be beneficially linked. From site organization to unit organization, energy consiousness and responsiveness to user needs guide each design decision. This is done while being mindful of the costs along the way. The resulting architecture is a significant answer to the need for economical public housing that takes advantage of the abundant energy falling as sunshine around us.

Underlying the goal of using solar energy to heat the homes of poor people are several factors urging for energy conscious design in urban multi-family housing.

One, the tremendous amount of energy used for residential space heating makes housing the clear target. Commercial and residential energy use accounts for 33.6% of the national energy consumption. Of this, 53% goes into space heating.[1] Urban multi-family housing in particular is an important sector of the housing market that has been all but neglected by solar energy literature. Countless solar home texts emphasize a piecemeal, single family detached housing approach to solar. To date the experiments in solar dwellings have been singular efforts, specific to their sites and custom designed. The degree to which solar becomes part of the world energy answer, is dependent on its successful incorporation into and impact on our way of life. Bringing solar energy on line requires its large scale use. Thus, a multi-family urban building type with solar technology can have a significant impact on overall energy consumption.

Currently, two major forces are pushing urban housing to the center of attention. From a need perspective, all major cities have severe housing needs. And most of those in need of this housing are poor people for whom cities have been and often remain the sole locations of affordable shelter. Add to this the rising cost of single family housing in America spurred by skyrocketing costs for construction, land and fuel. The possibility of suburban home ownership moves away from the reach of middle income people and completely out of sight for low-income people.



SUBURBIA,
a prominant symbol of the
era of energy wastefulness.
Source: Schoolhouse.

This situation has brought many upper income people back to the city; upper and lower income people are now competing for the same scarce housing. Thus, there is added pressure for more urban housing which, with its higher density, holds great promise for meeting future housing needs.

From an energy perspective, urban housing is part of a sensible development pattern. When the whole energy consumption and conservation picture is evaluated, land development practices must be considered carefully. Our present land development tendencies have far greater impact on energy consumption than any other single energy conservation measure or solar technology application. Additionally, land is as precious a commodity as energy. Multi-family attached dwellings conserve land and energy. An urban location also offers residents the proximity to work, recreation, shopping and cultural activities as well as mass transportation networks and existing infrastructure. Higher density living also allows for greater interaction between people and more opportunities for strong social ties. The whole living environment is more vital than in suburbia.

When looking at subsidized urban housing, its less desireable aspects cannot be disregarded. Many of the aspects stem from negative attitudes toward low income people and they become physical realities in public housing. In public housing people are unable to alter their homes because they do not own them. There is no allowance for individual expression or personalization and people must relinquish their identities. Open spaces are ambiguously owned and therefore people feel no connection to the land on which they live. When people feel unrelated to their environment social networks break down and living situations can become dangerous. To be a livable solution, these problems must be addressed by new attitudes toward low income housing. Such housing must respond to the spiritual and symbolic needs of the inhabitants.

The design of responsive housing also includes a new attitude towards nature and buildings. This is the second impetus for energy conscious design.

Employing solar energy in an urban setting presents many obvious difficulties---the logistics of solar access being the main

NEW TOWN COURT, Cambridge, Ma., is an example of the three-story public housing built in the 1950's. The courtyard space is asphalt and access to it from the units is limited to the single entry shown. All the units are masked behind the flat, experssionless face.

obstacle. However, the urban context also offers an exciting design challenge. It provides an opportunity to explore the full application of new technologies and the creative use of proven concepts. Most of our buildings with their mechanical environmental maintenance are divorced from experimental reality. The esthetics of architecture extend beyond visual impact. The relationship between people and building involves the experience of the full context, full perception of touch, sound and smell. Buildings, architecture, like people are exposed to nature and are surrounded and affected by it. Buildings also have the characteristic of being objects in time and space. They last over a period of years and witness and experience changes. Even within a day or season there are changes that go on around that can be reflected in a well designed building. It is most appropriate that architecture express this interaction between man, nature and buildings. A passive energy conscious design uses the shelter to modify the thermal, atmospheric and luminous forces acting upon it. This is the ideology embraced by passive solar architecture.

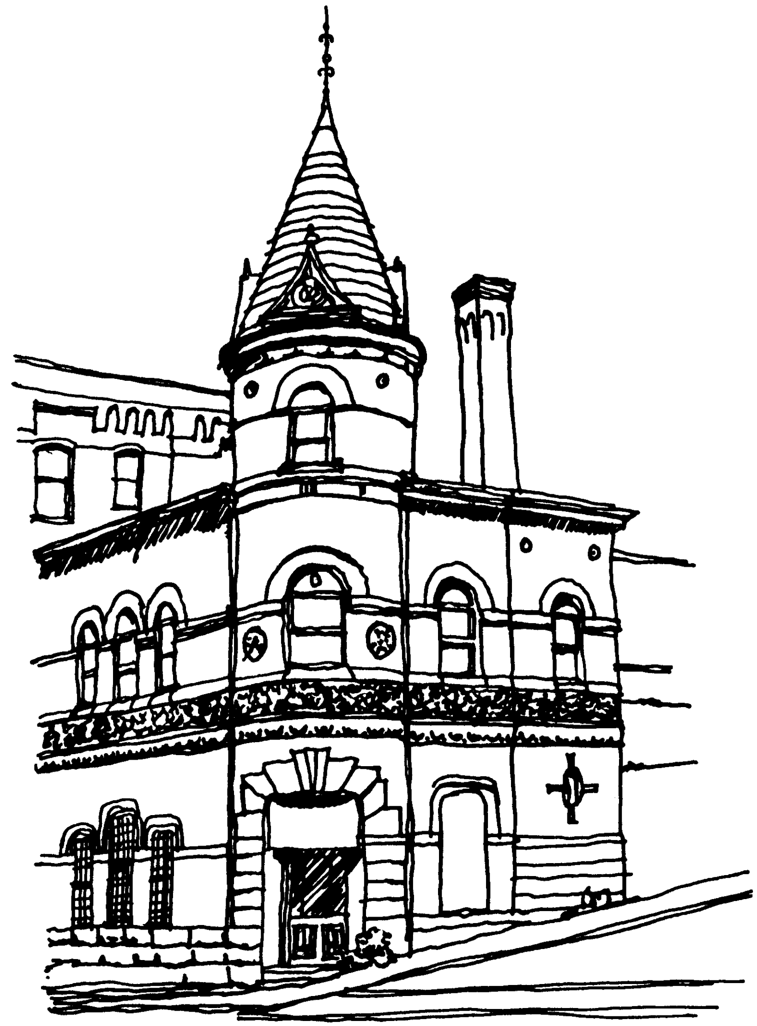
CHAPTER 1
SITE ANALYSIS

THE SITE HISTORY

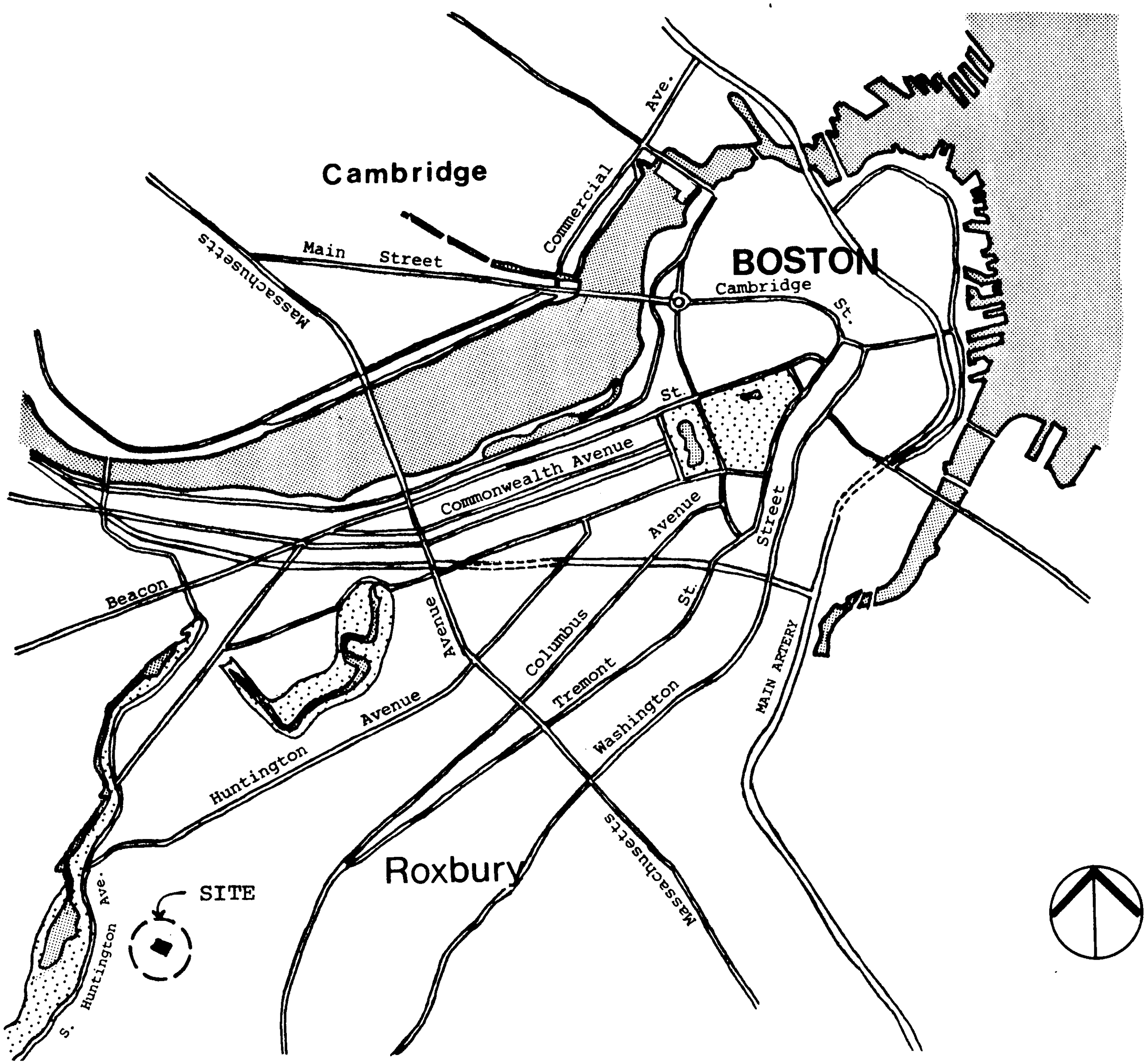
The proposed solar community is for a 1.33 acre parcel of/and on the southwest facing slope of Mission Hill in the Roxbury section of Boston. Four streets bound the site: Fisher Avenue and Hayden, Lawn and Estey Streets. It is in the area known as the Back of the Hill. Atop Mission Hill to the north is the hospital district. The vacant property is on the fringe of what was once a strong neighborhood of owner-occupied triple deckers.

During the early 1900's farmlands and estates in the area were consumed by development and the Back of the Hill became a working class community. Several large brick industrial buildings were also built (and continue to be occupied). Just over the hill, numerous hospitals sprang up. The residents of this area were primarily white until the Bromley Heath Housing Project was constructed in the 1950's and new black families moved into the area.

Radical changes came in the mid-1960's



THE OLD BREWERY on the corner of Estey and Heath Streets...one of the many brick buildings still in use.

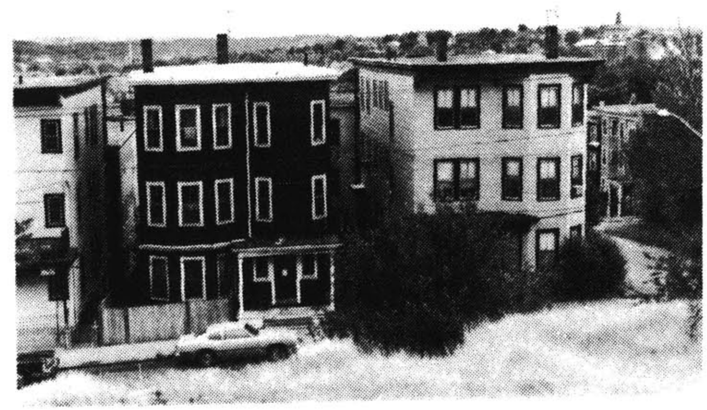


Vacinity Map

when some 18 acres of land were bought and cleared of homes for the expansion of the Lahey Clinic. The Ruggles Street Baptist Church began block busting and also purchased land for expansion. In 1971, after the majority of the houses had been demolished, both of these institutions abandoned their expansion plans. This left "over half the neighborhood a desolate, dangerous wasteland."[2]

Soon, developers began to propose various infill housing schemes which presented serious threats to the quality and character of the Back of the Hill. The remaining residents realized that only through organized efforts could they protect the future of their neighborhood. They formed a coalition that worked to maintain the integrity and safety of the community. Out of this coalition grew the Back of the Hill Community Development Association (BOTHCDA). The Development Association turned its attention to redeveloping the neighborhood. The residents felt it was important to keep the area affordable to low and moderate income people. (The median income on the Back of the Hill is $3,892 a year). Gentrification may not

THE TRIPLE DECKERS of the Back of the Hill. These are among the few remaining clusters along Fisher Avenue.



BRIÇK WAREHOUSE along Heath Street
now houses an auto service shop.

have been an emminant threat to this neighborhood but, this concern (or feeling) on behalf of the residents stemed from a recognition of current trends in urban centers. Thus, a lengthy battle ensued with the Lahey Clinic and in 1978, BOTHCDA was able to purchase a portion of the vacant land with an option to buy another ten acres. The ten acres include the 1.33 acre project site. In 1980, a 12 story handicapped and elderly tower was constructed on the first property along South Huntington Avenue. A proposal was under consideration for the development of moderate income single family detached homes on the remaining ten acres. Unfortunately, a cost analysis by the Greater Boston Community Development Corporation showed that such housing would be beyond the reach of the intended families. The BOTHCDA therefore, became interested in attached rental subsidized housing. The community's objectives are essentially the same; the new housing is supposed to reknit the neighborhood fabric and the targeted dwellers are low and moderate income families. It is also desired that these homes be heated with solar energy.

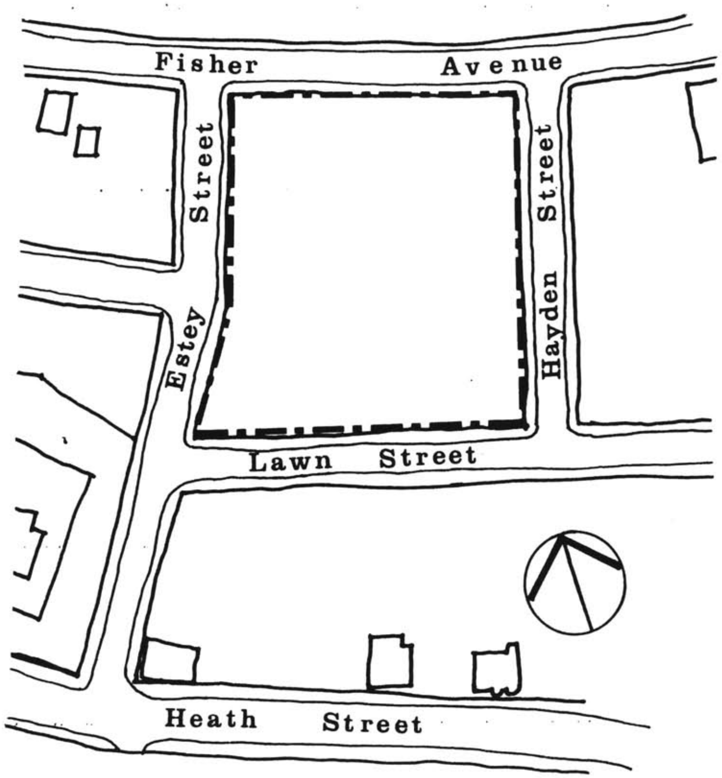
SITE ANALYSIS

Many positive aspects can be noted in regards to the project location. Unlike most public housing, this development is on prime view property. From the site, the 180 degree view of the Leverett Pond Parkland and the Boston outskirts beyond, is spectacular! The only element that detracts from this beautiful scene is the monsterous 11-story Vetrans Administration Hospital to the southwest. The hospital has a negative impact because its scale materials and morphology have no relation to the context.

Good services abound in this area. Two shopping areas are within half a mile and access to them via public transit is just minutes away. The Arborway trolley line runs along South Huntington Avenue, and The Link, a local shuttle bus, services the top of Mission Hill along Fisher Avenue. Public transportation also connects residents to nearby cultural attractions and educational institutions. Open space recreational facilities are within walking distance.

VIEW FROM TOP OF MISSION HILL
Bromley Heath Housing Project is in the middlegorund.

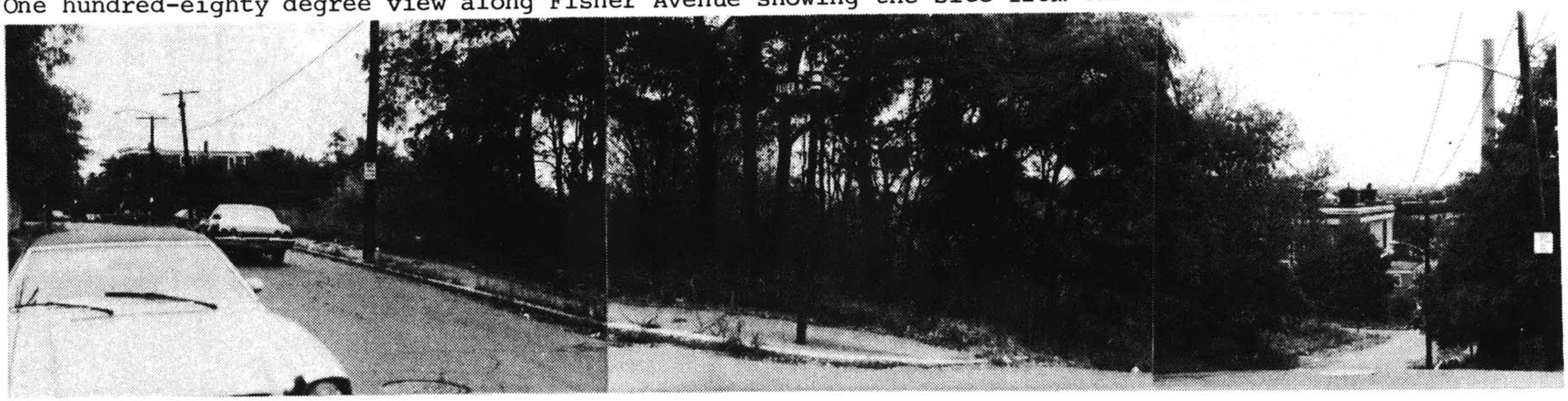
THE VETRAN'S ADMINISTRATION HOSPITAL



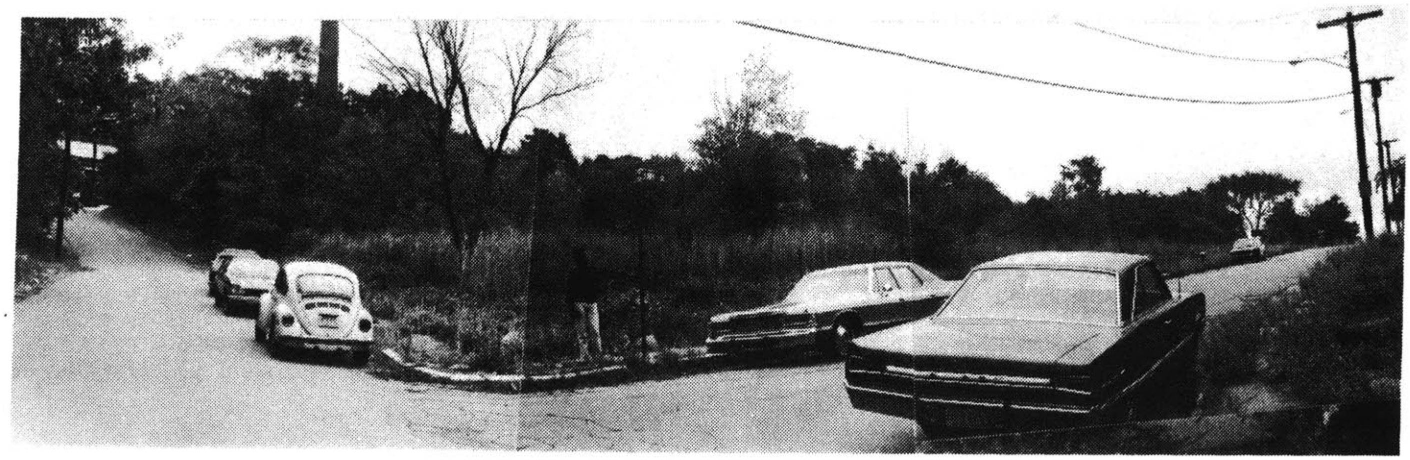
Public utilities already exist on the site, remnants of the previous development.

A big plus for the site is the fact that the adjacent neighborhood is pushing for its actualization. The residents of this new housing will be of income groups similar to those of the present Back of the Hill residents. Unlike the South End or other parts of Boston, community pressure will not allow this particular area to be swallowed up by institutional expansion or gentrification. Thus, it provides a supportive environment for the project.

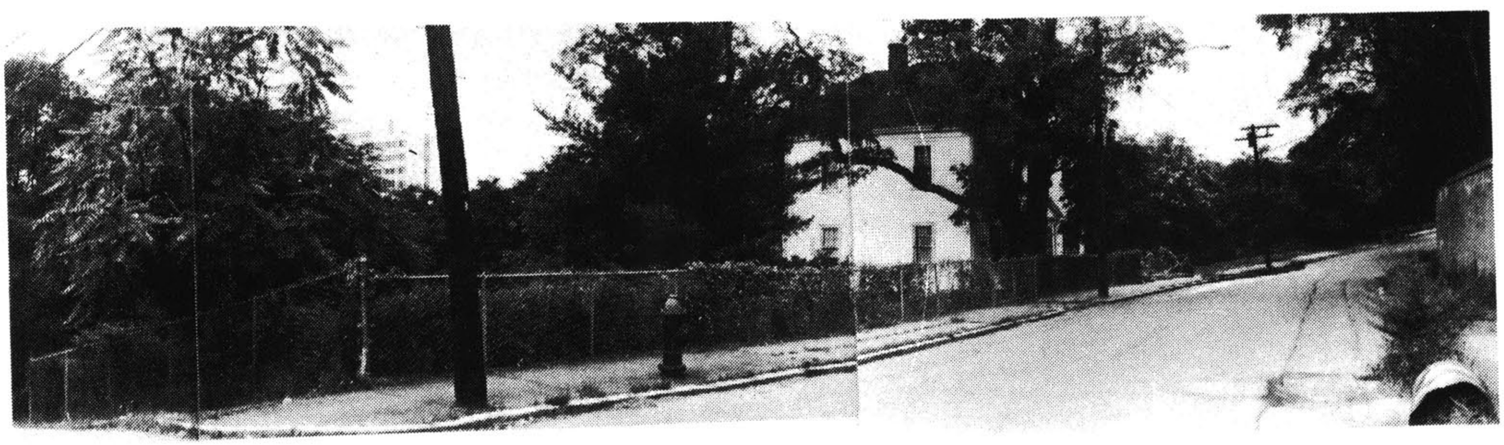
One hundred-eighty degree view along Fisher Avenue showing the site from the northwest

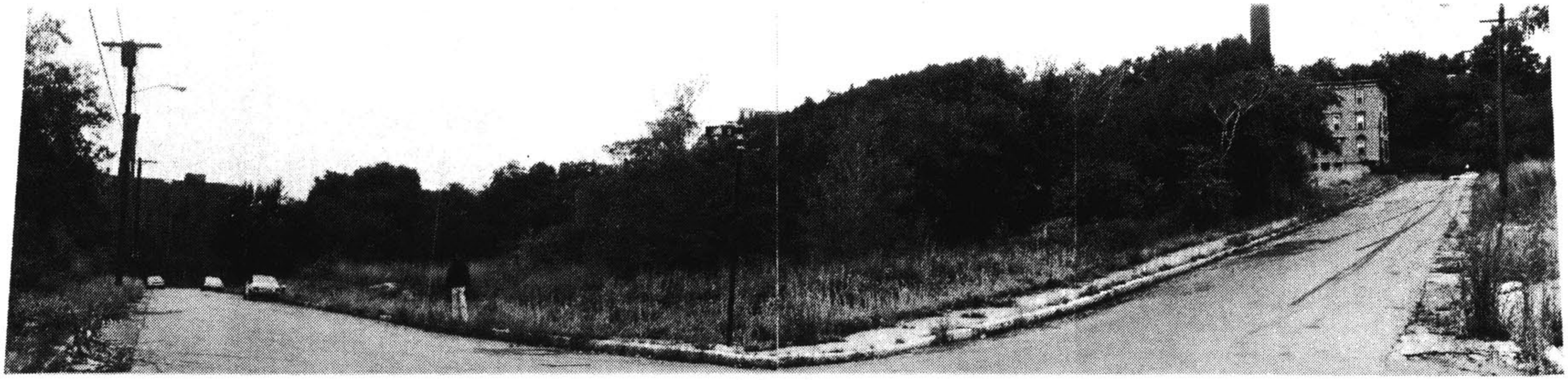


Site Views



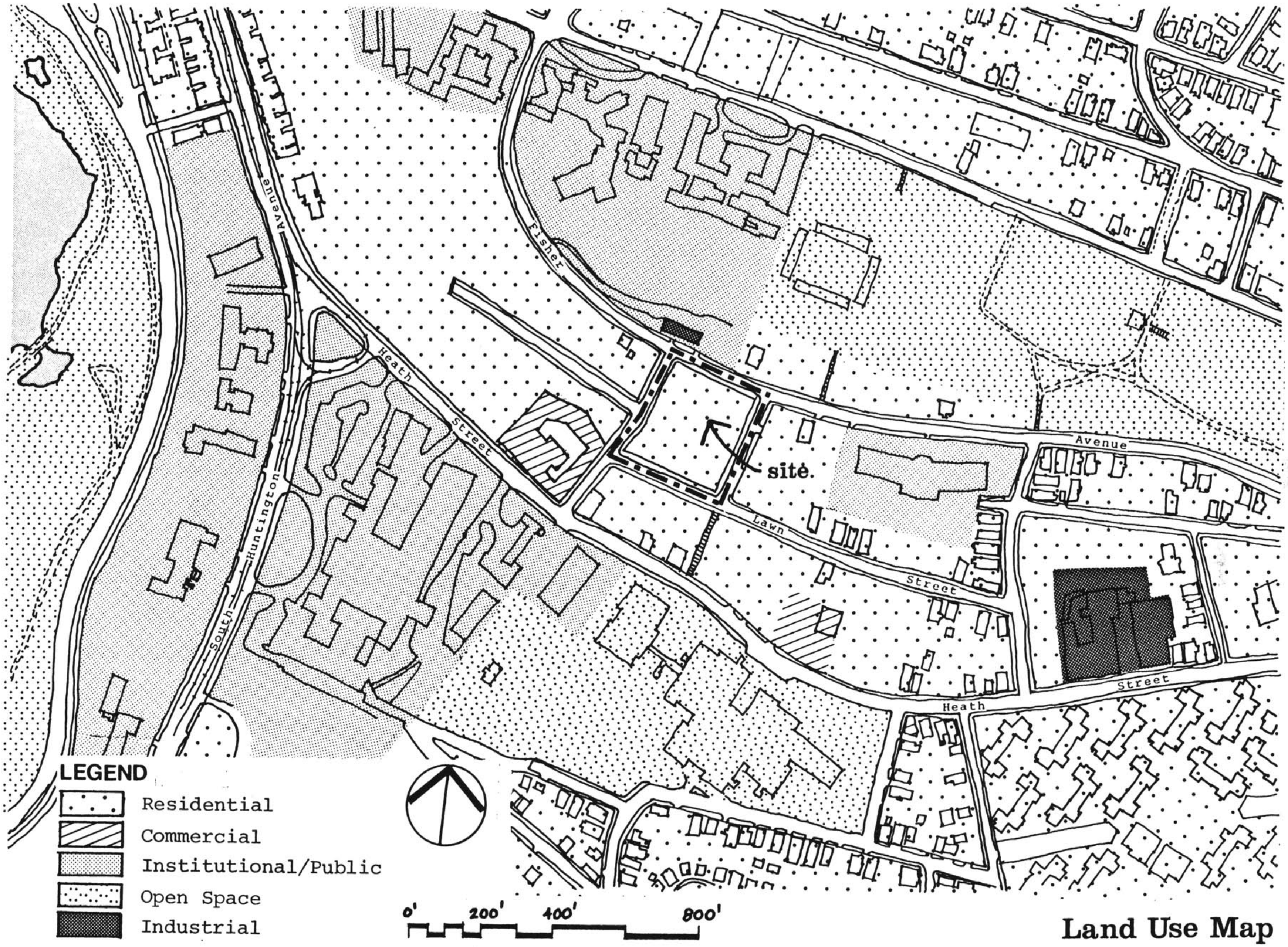
Site, viewed from the Southwest corner





View from the corner of Lawn and Hayden Streets (Pip is the scale)

The Panoramic view from the top of the site at the corner of Fisher Avenue and Hayden Street



Avenue
Huntington
South
Heath
Street
Fisher
site
Avenue
Lawn
Street
Street
Heath
LEGEND
Residential
Commercial
Institutional/Public
Open Space
Industrial
0'
200'
400'
800'

Land Use Map

MICROCLIMATE ANALYSIS

The greatest attractions of this location are its southern exposure and hillside topography. To design most effectively with these features, the entire microclimate must be understood. Solar access, insolation, wind and temperature are studied to identify their unique characteristics on this site.

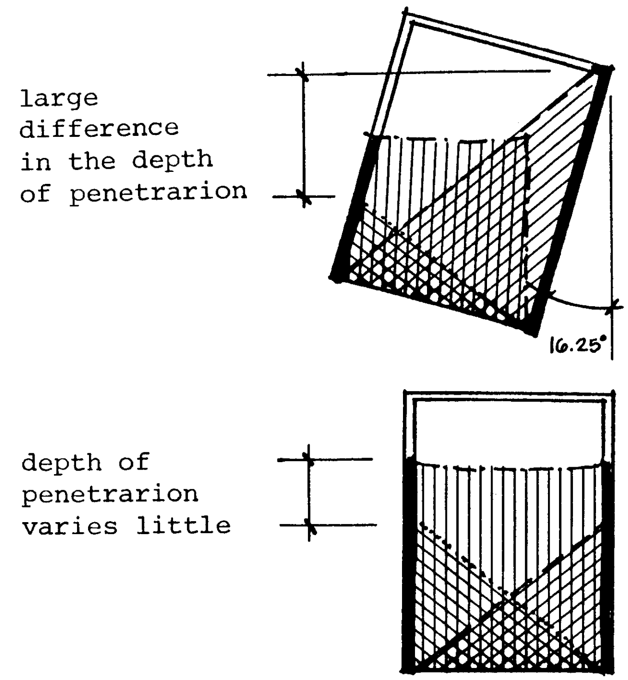
In solar design, the sun's path and true south are key factors in organizing the site and choosing solar technologies. Daylighting design and light directing techniques are also dependent upon the sun's location and seasonal course. Ultimately, this information determines the building configuration and detailing.

Locating true south was the first step in the microclimate analysis. At solar noon, when the sun reaches the highest point in its daily path, true south was located at 200.75°. Appendix 1b contains an explanation of the method used to pinpoint true south. This orientation is 16.25° east of the orthagonal configuration of the site. Site planning possibilities for resolving the descrepancy between the site orientation and true south are analysed in depth in Chapter 3.

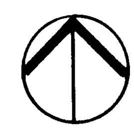
The behavior of the sun is relatively predictable for a true south orientation; patterns of shadows and sunlight penetration are symmetrical about 12 noon. When a different orientation is considered, additional analysis is necessary. In terms of natural daylighting design, it is possible to evaluate the impact of the descrepancy by looking at the daily change in the profile angle. The table in Appendix la compares the maximum and minimum profile angles for several southerly orientations. A graphic analysis of the two extreme orientations, is helpful in this discussion as well.

Comparing the true south and 16.25° off of south orientation on December 21, the profile angle swing increases by 7° for the southwest orientation. The diagram shows this increased fluctuation in the depth of penetration which is greatest during the afternoon and less in the morning. In either case, however, the same amount of wall surface receives direct solar radiation.

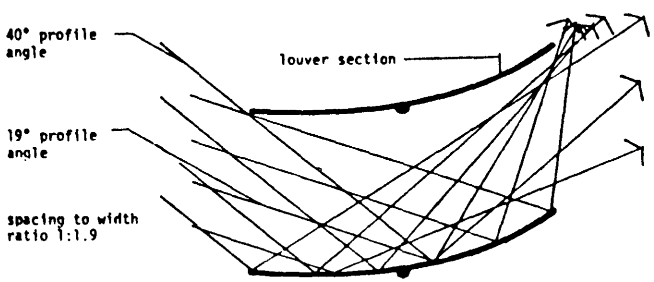
For light direction to enhance daylight



December 21 (9 am, 12 noon, 3 pm)



DEPTH OF PENETRATION for the south and southwest orientations is studied graphically.



THE MYLARIZED LOUVERS are bound by a strict geometry which allows light to be reflected between the blades. Disabling glare is created if light strikes the underside of the blades above. Source: M.I.T. Solar Building 5, p.14.

pentration mylarized louvers or a light shelf can be used. The information in Appendix 1a shows that the mylarized louvers could be used effectively only up to 10° off of south. Constant adjustments would be required if the louvers were used for the 16.25° west of south orientation. Based on the limited opportunities offered by the louvers, the light shelf was explored further. The light shelf was designed to direct winter sun angles between 30° and 50°. Because the light shelf is fixed, no adjustment is necessary or possible.

Modelling the light shelf design was the best way to assess the impact of the south-west orientation. A test was conducted with the daylighting model on a heliodon to simulate various times of the year, which quickly showed that the light shelf successfully directs light to the storage walls. This means of gross light directing is relatively insensitive to the shift in orientation. Unlike the finely adjusted louvers, the light shelf operation is not hampered by the fluctuating profile angle.

The final decision on building orientation can only be made after the solar technology options are fully explored.

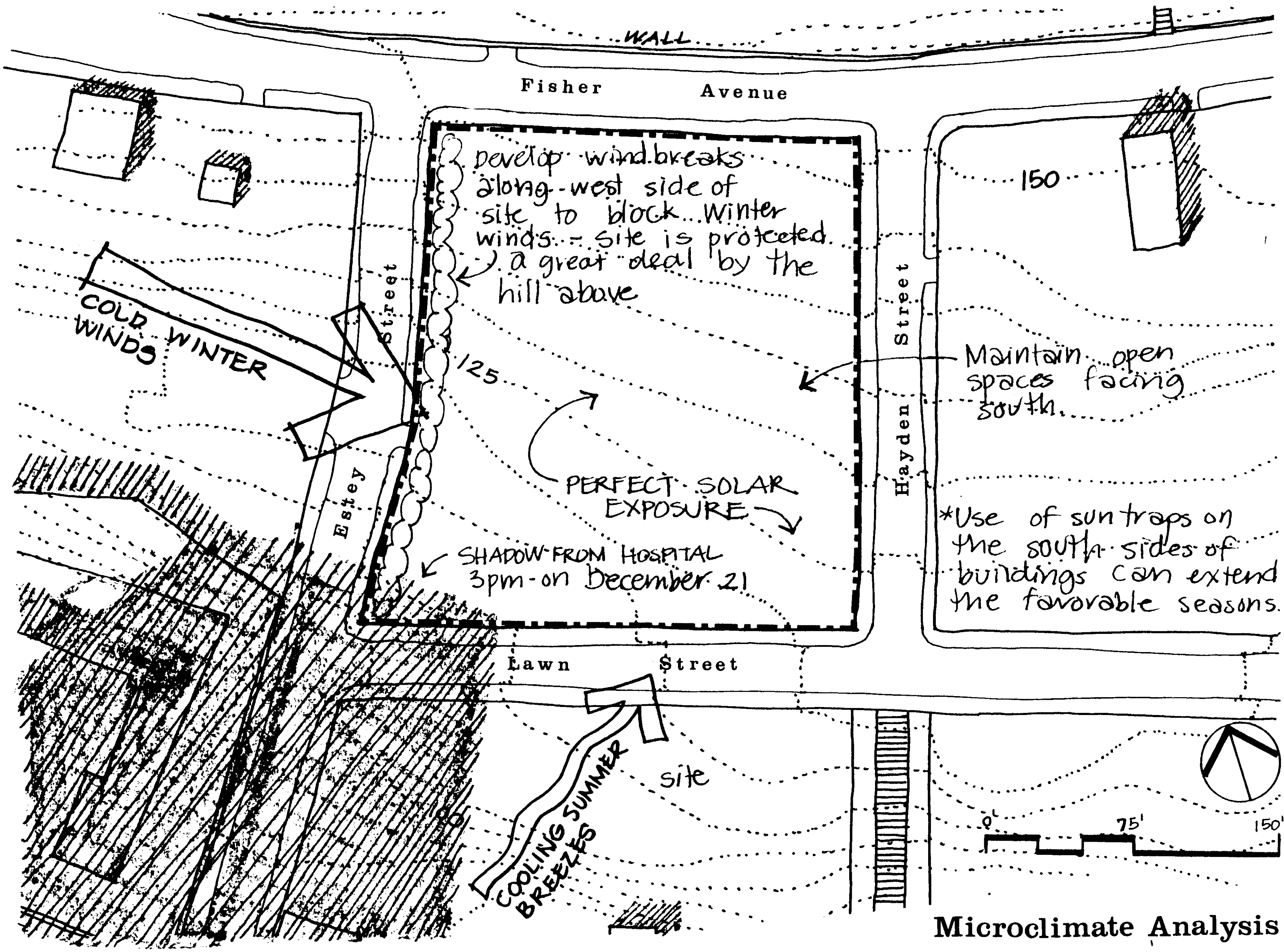
Once true south is located, the sun's path and possible solar obstructions can be determined. A device called a "sun machine" aids in this investigation. The machine is essentially a sight that may be set for the date, time, latitude and local declination. The sun machine was positioned at each corner of the site facing south. By rotating the mounting and looking through the sight, the course of the sun could be viewed. During the heating season between 8 a.m. and 4 p.m. the solar access is almost unobstructed. The only notable obstruction is the V. A. Hospital which shades the corner of Lawn and Estey from approximately 3:30 p.m. on in November, December and January.

Night Air Flows

Another site variable affecting the microclimate is topography. At night, convective currents of cold air may flow down such a sloping site. Improperly sited buildings can dam this cold air creating cold pockets which rob buildings of additional heat.

To check for cold air flows, air and soil temperatures are taken in spot locations around the site. Smoke is used to determine the direction and speed of any air movement. This is done on a still evening following a sunny day to ensure that the air movement is due to convection and that the land has recently absorbed heat. An 8° temperature difference across the site would indicate the presence of cold air flows.

The test was conducted twice and the data sheets can be found in Appendix 1d. The tests show that this cold air flow problem does not exist is in the middle of the larger slope. While testing, however, a rapid cooling was noticed. This probably results from the site's exposure.



Microclimate Analysis

CHAPTER 2

SITE DEVELOPMENT

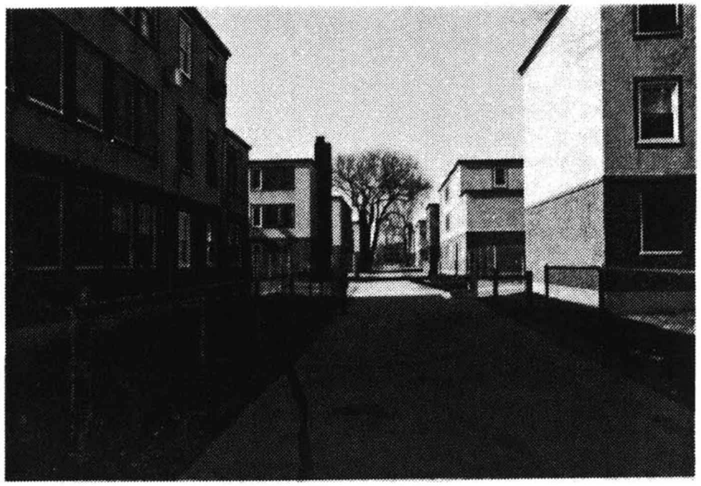
A Program for the Solar Community

The program for the passive solar housing is the result of discussion with Back of the Hill residents, John Sharratt, the architect for BOTHCDA and the author's ideas on improving living environments for low income people. Unlike the standard architectural program, this one is not in terms of square feet or room requirements. Instead, it outlines the special issues and concerns that are addressed in this thesis. Under the headings of user needs, energy consciousness and physical design numerous guidelines and objectives are set forth for quality and character of the housing to be designed. Incorporating these design considerations will help low income residents maximize the use and enjoyment of their homes.

PROGRAM

User Needs

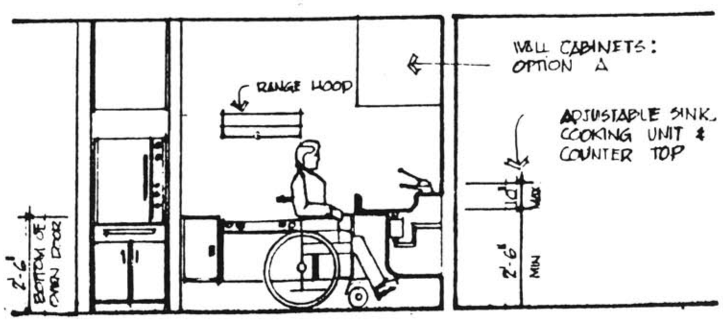
- Provide for privacy, territoriality and identity. The lack of these qualities or opportunities for their development have plagued public housing (and urban housing as well). People should be able to personalize and alter their homes and their immediate surroundings.



NEW TOWN COURT, Cambridge Ma.

- <u>The connection between people, nature and the built environment should be expressed</u>. Visual and physical links to the outdoors can be developed to reunite the urban dweller with the natural landscape. Each unit should have a private outdoor space for gardening and recreation to give people some sense of the ground their homes are built upon.

- <u>Handicapped and elderly accomodations must be included</u>. The Massachusetts State Building Code requires that 5% of the units in subsidized housing be especially designed and equipped for handicapped people confined to wheelchairs. Some of the thoughtful design features in handicapped units can be used in homes for elderly occupants.



MASSACHUSETTS HANDICAPPED CODE
Minimum dimensions and requirements

- <u>A balanced and diverse community is essential and desireable.</u> Residents of this housing should be from various ethnic and racial groups as well as low and moderate income groups.

- Home ownership and rental opportunities should be encouraged. Traditionally, the neighborhood has had a mix of renters and homeowners. This should be maintained to provide a choice of housing options. Home ownership should be explored because it enhances the neighborhood by establishing a permanent, stable population of ownership which can lead to better maintained property, reduced crime, and heightened sense of community.

- The unit mix should reflect the need for larger family homes. Two bedroom units are most commonly built in public housing because they have the highest living space to plumbing space ratio. However, this leaves many larger families without proper housing. These large families should find homes in this new development.

- The housing should be moderate density. Since the density of this housing should be appropriate for family living. Undoubtedly there will be more units per acre than in the existing triple decker neighborhood, but it should not exceed 60 du./acre which is considered high density.

Energy Consciousness

- Independence can be achieved through the use of solar energy. Using this source of free renewable energy promotes self-sufficiency. This should be the idelogical foundation for the project.
- Natural site features should be fully exploited. This site is nearly perfect for solar energy use. There is an unobstructed southern exposure and a sloping site that increase the solar access. Solar heating should be one of foremost considerations in concieving this new housing.
- Energy savings should benefit the low and moderate income residents. Residents should directly realize energy savings through either maintained low rents which do not reflect the increasing price of fossil fuels, or lowered life-cycle operating costs.

Physical Design

- Natural site features should be fully exploited The site topography offers a grand opportunity for a unique site organization. This can be done in a way that enhances both the site and the housing.

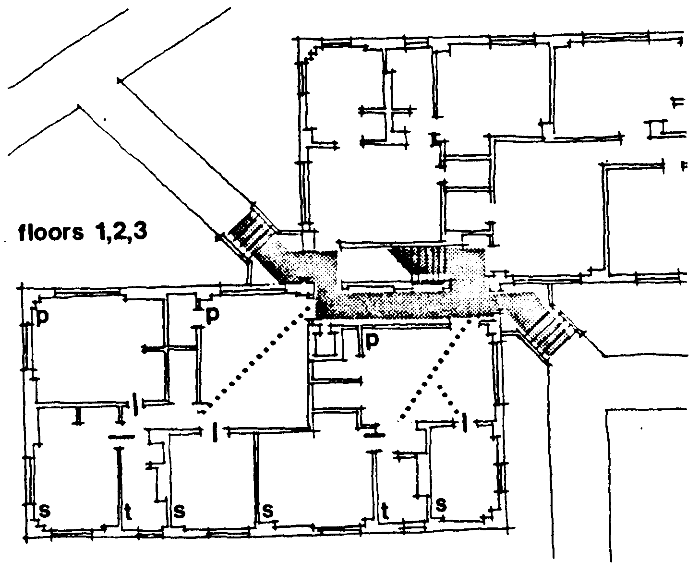
- Historical references can be used to enhance the housing design. The introduction of historical imagery or elements in the new development can strengthen its relation to the existing neighborhood.

- The new housing should visually and physically reknit the neighborhood. The massing, scale, height, shape and materials of the indegenous buildings offer design clues for the new housing. New pedestrian movement patterns can be blended into existing networks.

- Perception of Density can be controlled by physical design. The sense of overcrowding or high density can be avoided by using unit clusters or short rows of attached dwellings. It is also useful to minimize the number of units visible at once.

- Units should have distinct public and private sides. Public housing design often overlooked the need for public and private edges. At least one side of each unit must be private in terms of use, views and noise.

THE HAYDEN STEPS
are a prominant historical reference on the Back of the Hill.



INTERIOR ACCESS CORRIDORS
and double-loaded corridors, as used
in public housing, should be avoided.
When too many units share these corridors,
the living situation can become dangerous.
Source: Tractibility in Housing.

• Outdoor spaces should meet a variety of needs. Private outdoor spaces should be connected directly to interior living spaces to enhance their use. Daylong sunshine should be taken advantage of whereever possible. Both hard and soft surfaces should be provided to accomodate different activities. Large common spaces should be provided for group functions or sports. Parking areas can double as recreation space.

• All units should have direct access. The entries and passage to each unit should be visible from the street or car drop off points. This measure avoids the dangerous indefensible interior corridors that are so prevalent in urban public housing.

• Centralized and decentralized parking should be employed. By grouping some parking in a central convenient location, useful sized open spaces for public and private use are liberated. Decentralized parking allows people to park adjacent to their units.

HOUSING COSTS AND FINANCING

The next step in the project development is to look at housing costs and financing mechanisms. The following discussion is based on the cost calculations that can be found in Appendix 2. These numbers are not intended to be exhaustive or particularly rigorous. Instead, they are ballpark estimates used to generate the quantative aspects of the program. Information for these estimates has been gathered from numerous sources including the Boston Community Development Corporation and HUD.

The program elements directly related to cost and financing are:

1) moderate density
2) low to moderate income residents
3) homeownership and
4) passive solar energy use

Density

The cost analysis, like the building process works from the ground up. So, the first consideration is the cost of the land. In subsidized housing this is often the factor contributing most to the quality of the housing environment. Subsidized housing is usually built on low-cost land or at extremely high densities to minimize cost or maximize profit. To meet the program objective of moderate density and find an economically feasible density is a balancing act.

The easiest way to obtain an affordable density is to aim for a certain land cost per dwelling unit. On the average, land, including developing costs, accounts for $2,000 to $3,000 of the unit cost in subsidized housing. The 1.33 acre parcel with its $94,995 price tag must be developed with 45 units to bring the land cost down to $2,021. This yields a density of 33.8 du/ac (dwelling units per acre) which falls into the moderate density range. This estimate provides a base for the site planning phase.

HOMEOWNERSHIP AND MODERATE-INCOME RESIDENTS

The program concern for low and moderate income residents is related to the recommendation for homeownership and therefore the two should be considered together. The possibility of homeownership heavily depends on the residents' ability to meet the mortgage payments.

The GBCD investigated home ownership opportunities for moderate income buyers. Their method of estimating housing costs is used in Appendix 2b to find the monthly payment for an average-sized home on this site. For owner-occupied housing, the monthly costs would be $711. The low or moderate income resident must shoulder this entire cost which includes the debt service on the mortgage property taxes, insurance, utility costs and developer's profit. Lending institutions figure that thirty percent of a family's annual budget goes toward housing. To meet these monthly payments, a family's income would have to be $28,440, which is above the moderate income level in Boston. It must also be noted that the debt service calculated is based on a 20%, or $13,166, downpayment. It is unlikely that a low or moderate income family could make such a downpayment. These results show that is too expensive to build moderate income owner-occupied housing on this property.

The $711 figure above also represents the market rate rent on this typical housing unit.

This is quite in contrast to the medium monthly rental payments in Roxbury, Jamaica Plain and Dorchester which ranges from $120 to $160, including heat.[3] In order to benefit low and moderate income people, this new housing must be rentable in this range. This situation strongly suggests the development of the site with subsidized rental units. HUD's Section 8 Substantial Rehabilitation program is the most likely source of funding for such a venture. Under Section 8, residents must pay a fixed 25% of their income for housing and the difference between this sum and the market rent of the unit is subsidized by the government. The price of this average unit falls within the fair market rent guidelines set for Section 8 housing units.

As the prospect of homeownership grows dim, developing housing with alternative ownership possibilities becomes more promising. Two options are explored below.

Cooperative housing offers many of the advantages of homeownership and renting. Living units are jointly owned by the members of the cooperative rather than individually. Yet, residents get the same tax benefits as private homeowners. Like renters, cooperative members may move at any time. However, there is no obligation to sell one's unit or break a lease. The best feature of this scheme is the member-based control. The cooperative organization actively involves each resident in the community and its operation maintains the social networks between residents.

Another possibility could allow renters to purchase their units. The housing could initially build as rental units with Section 8 money for example. Then, renters could lease their units with an option to buy them using long-term financing. This serves the immediate needs of renters and those of prospective owners. Perhaps this is the best solution because it produces a mixed neighborhood of renters and homeowners.

TRADEOFF METHOD AND THE SOLAR BUDGET

The key to implementing passive solar heating in subsidized housing is cost. It is doubtful that solar heating will ever be employed in such housing if it increases the housing cost by thousands of dollars. Throughout this thesis, a method of dollar-for-dollar tradeoff is used to absorb the cost of the passive solar energy system in the present unit cost. A "solar budget" is created by selecting alternative building materials, equipment and systems that cost less and work in concert with the passive solar concept. The dollars that are saved in heating bills over the first three years are also added to the "solar budget". Then, the money is "reinvested" in the actual components of the solar heating system. Appendix 6 shows the final cost balancing sheet.

CHAPTER 3

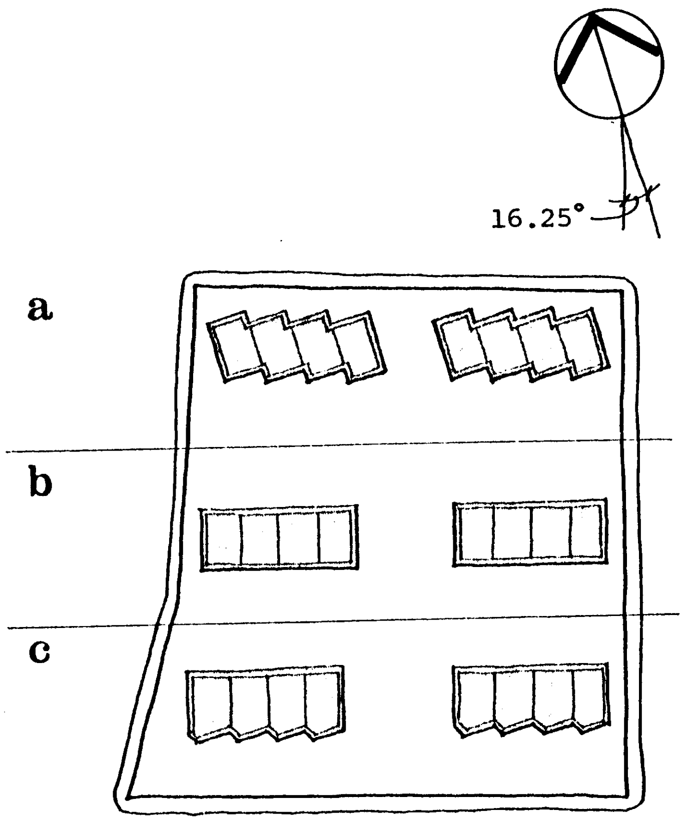
SITE ORGANIZATION

SITE PLANNING AND ORGANIZATION

Site planning begins as a response to microclimate conditions. Sun, wind and temperature all have significant roles in shaping the use of the land. Once these microclimate features are understood, they can be mitigated or utilized to enhance human comfort. Microclimate analysis is often used to select the best building location on a site. Since the entire site will be developed in this case, the microclimate information help in determining the problem areas on the site. Where microclimate conditions are unfavorable, it is possible to alter the environment through design to produce the desired conditions.

Perhaps the foremost climate feature to be considered in this design is the sun. To employ solar energy for heating in multi-story dwellings of this density, solar access becomes a critical issue. Solar access impacts the location, orientation, form and volume of the buildings on the site.

Regardless of the particular passive solar system selected, the orientation of the units

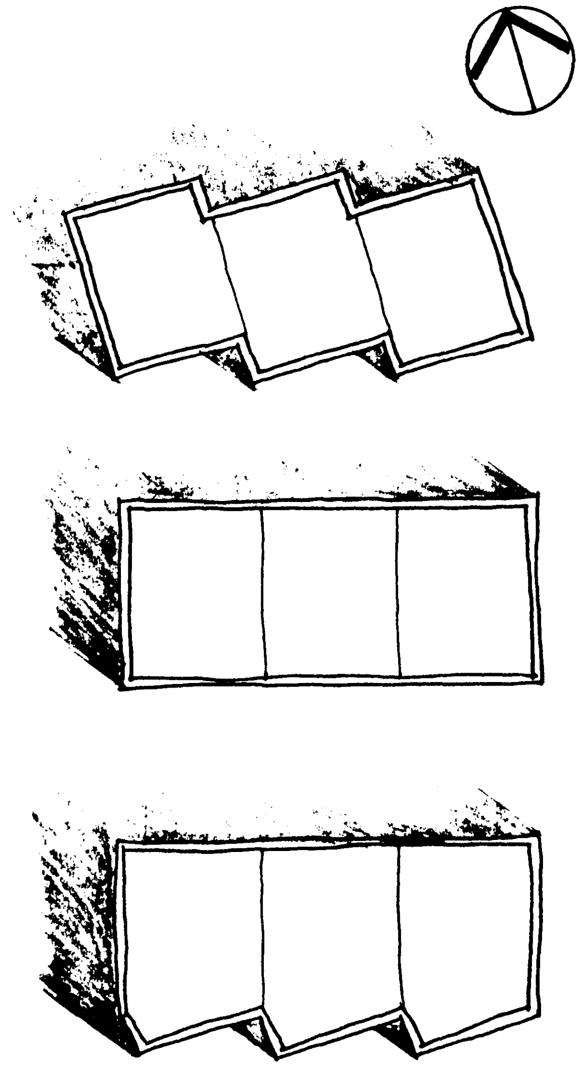


POSSIBLE HOUSING CONFIGURATIONS
a. due south orientation
b. following the site grid
c. saw-tooth south facade

with respect to south is important. Proper orientation coupled with energy conservation through tight construction can drastically decrease the heating load on a building. As noted in the microclimate analysis section, the orthagonal street grid around the site is 16.25° southwest of true south. In addition to its impact on light redirection, this discrepancy affects the total amount of radiation the unit receives. It is possible to orient the buildings according to the street grid which reduces the solar intake. However, if capturing 100% of the potential solar energy is desired, several options are available. The buildings can be oriented due south without regard for the street grid. The buildings themselves become staggered in this case. Another option is to turn one surface of the dwelling to face south while the rest remains true to the street grid; this produces a saw-tooth building facade. A fourth option is to choose a multi-directional polygon, whose geometry provides surface in numerous directions. Each of these options has different architectural implications as well as impact on solar access.

Shadow studies are shown for three of the solutions described. The shading of adjacent units produced by the southern orientation reduces the amount of radiation striking the south facing windows more than does the south-west orientation. An unusual geometry is an expensive propostion which is beyond the budget of subsidized housing. The saw-tooth facade approach seems to work well for intercepting the sun's rays. Yet, it does not have a distinct advantage over the buildings aligned with the street grid. For a direct gain system the exposure of the thermal mass is most important and both options expose the same amount of storage surface to direct sunlight. According to Edward Mazria's Passive Solar Engery Book, the indicent radiation on a surface 16° off of south is only diminished by 4%. Since the reduction in solar gain is small, the buildings were oriented in congruence with the street grid.

Concurrently, the building form was considered. At this latitude, 42.2°N, a building elongated along its east-west axis allows the greatest southern exposure for solar collection during the winter when the sun is

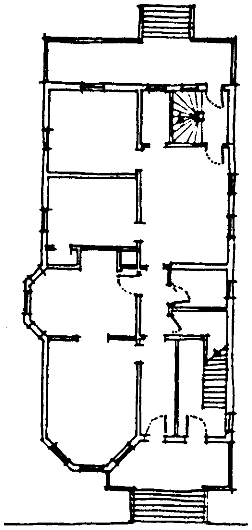


a

b

c

Shadow Studies

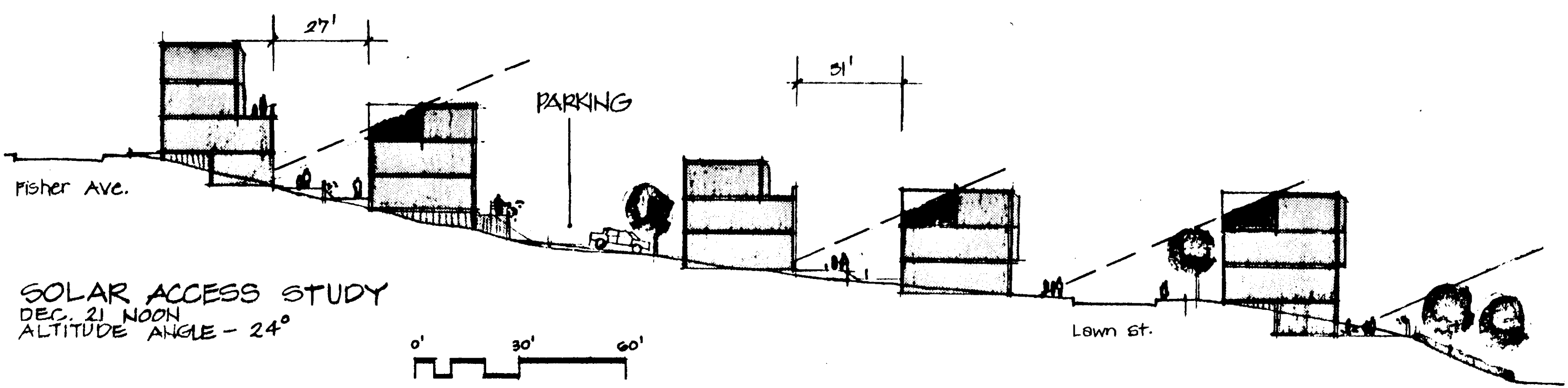


PLAN OF TRIPLE DECKER
Proportions vary from 3:1 to 2:1. Source: Tractibility in Housing.

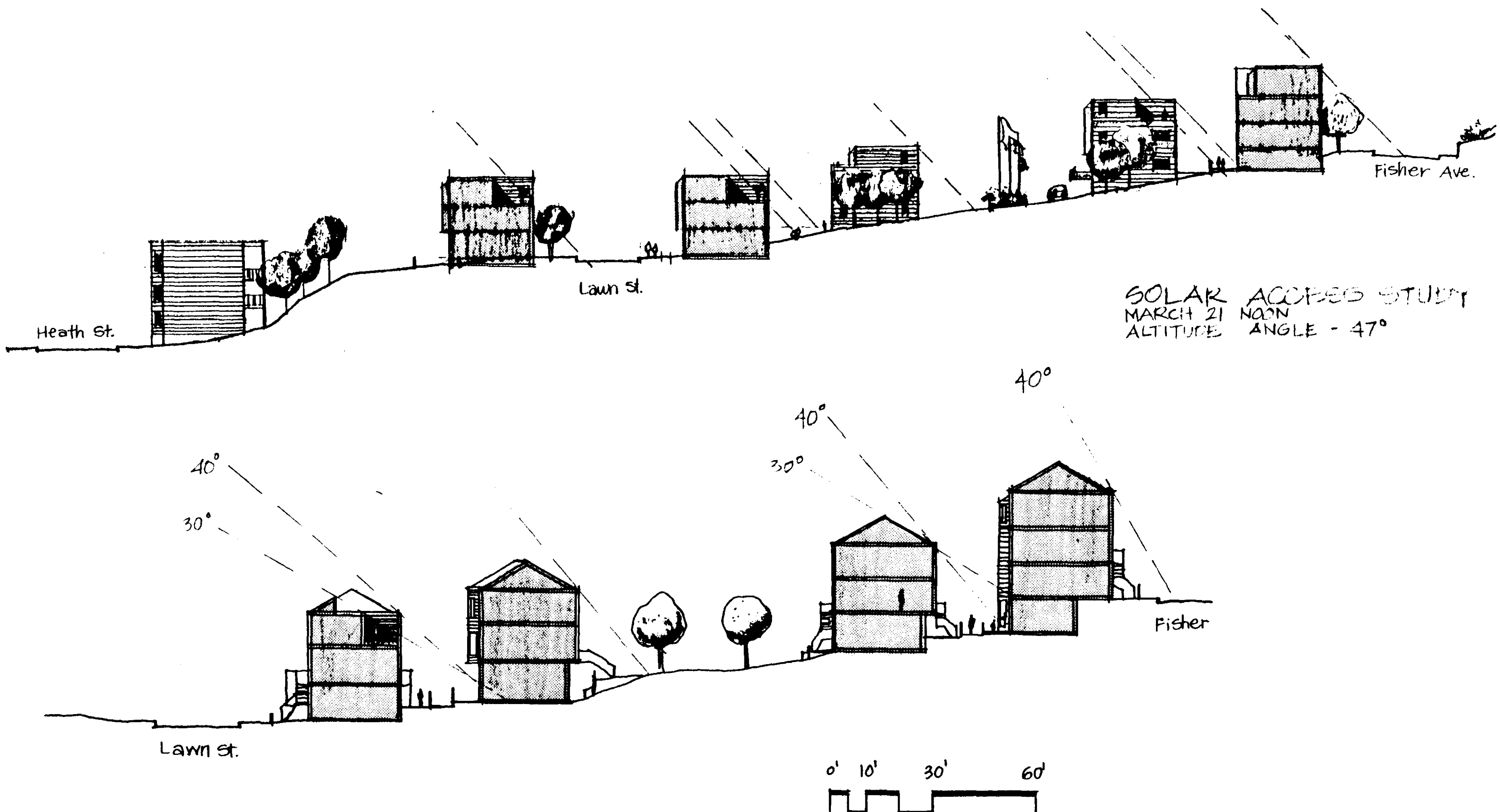
low in the sky, striking the south face. This shape also reduces the east and west faces to minimize the summer heat gain.

Maintaining the imagery of the triple deckers was possible with modified proportions. The standard triple decker or row-house proportions vary from 3-to-1 to 2-to-1 which changed in the individual units to 1.4-to-1 or -1.17. These shapes also translate into appropriate unit module sizes based on the Minimum Property Standards guidelines.

Once the building orientation and basic plan configuration were determined, a building envelope was established to avoid solar access conflicts. Both graphic methods using solar angle projections and three dimensional models were used for this.



SOLAR ACCESS STUDY
DEC. 21 NOON
ALTITUDE ANGLE - 24°



Solar Access Studies

The physical solutions suggested by these studies are combined with the program and architectural requirements for the site to yield the final site plan.

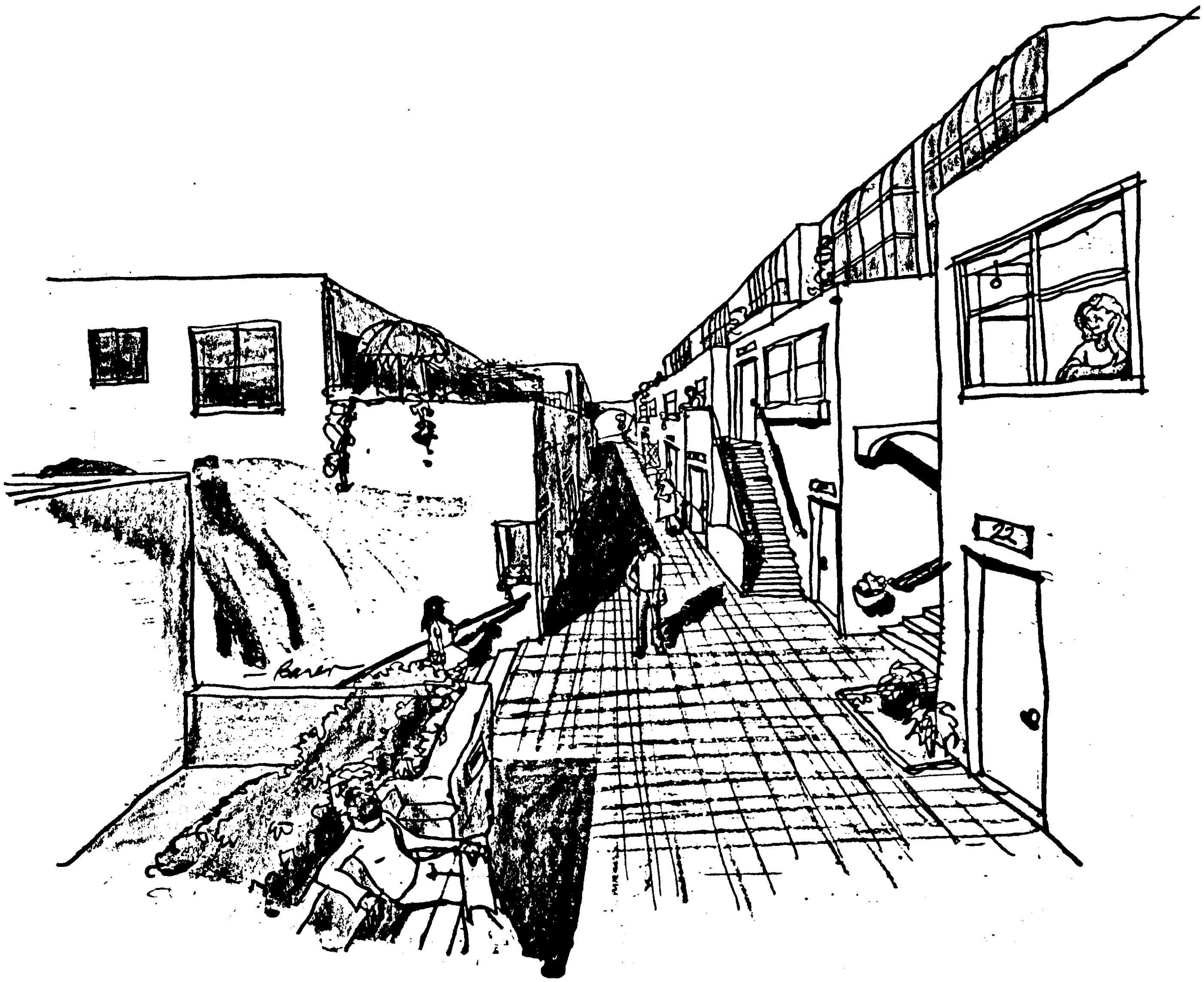
ARCHITECTURAL AND PROGRAM RESPONSES

The site planning for the design capitolizes on the site's natural and man-made ammenities. The design also overcomes numerous problems often associated with public housing.

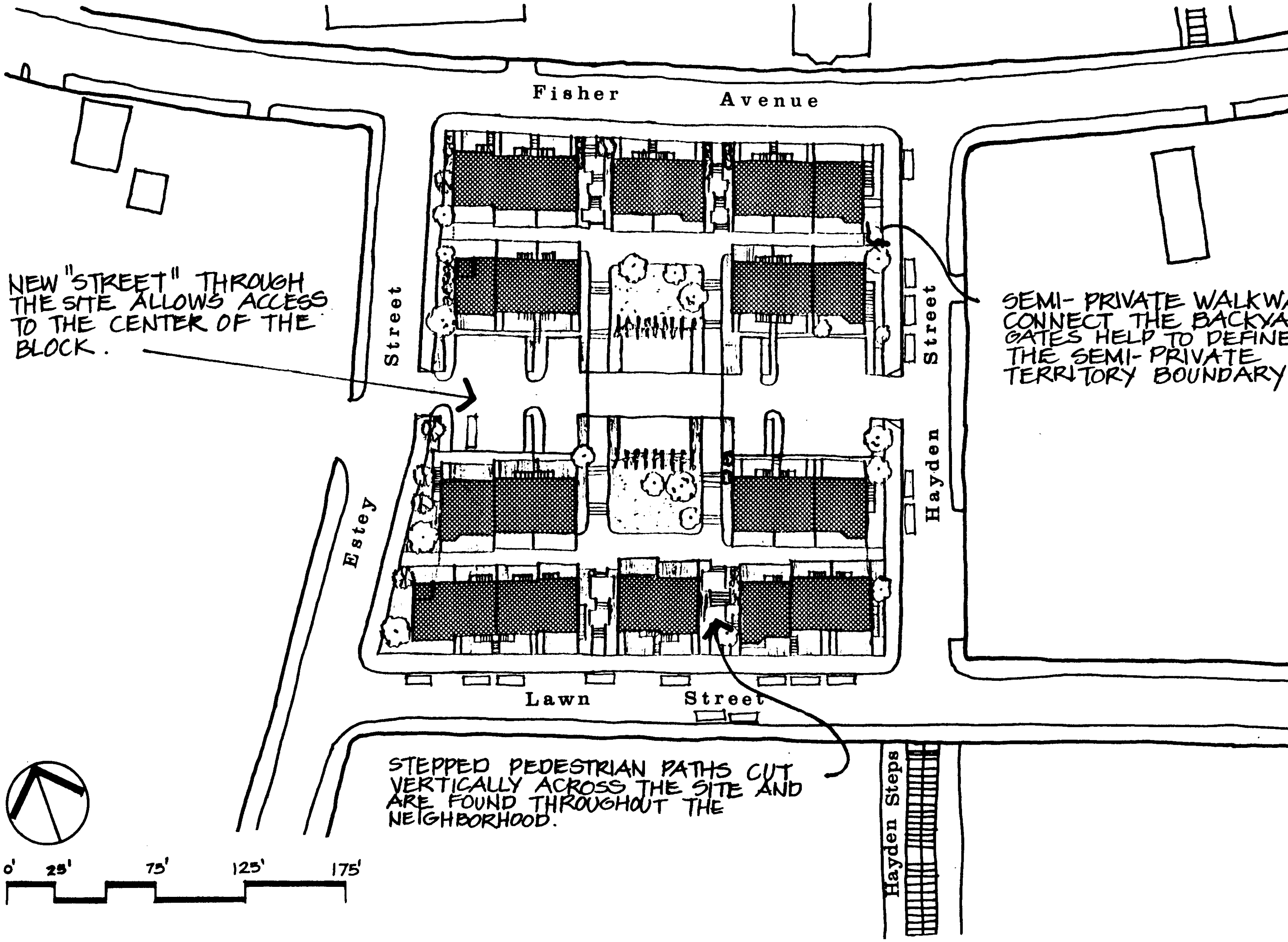
Public housing projects typically break with the established neighborhood pattern. Instead of maintaining residential-scaled blocks with street related dwellings, super-blocks are created with buildings situated around interior courtyards. The buildings themselves are very institutional, lacking variation or definition between individual residences. Public housing residents are physically and psychologically isolated from their surrounding communities. This stigmatization can be eliminated by physically weaving the new housing into the existing fabric.

The basic site organization is reminicant of an Italian hilltown. Short rows of three-story attached houses stretch horizontally along the contours. By working with the contours, the required excavation is minimized. As the houses step up the hill, the upper units attain panoramic views to the Leveratt Pond

HILLTOWN OF PISTICCI, ITALY
Source: Italian Hilltowns



Initial Design Sketch



Fisher Avenue
NEW "STREET" THROUGH THE SITE ALLOWS ACCESS TO THE CENTER OF THE BLOCK.
Street
Street
SEMI-PRIVATE WALKWAYS CONNECT THE BACKYARDS GATES HELP TO DEFINE THE SEMI-PRIVATE TERRITORY BOUNDARY.
Hayden
Estey
Lawn Street
STEPPED PEDESTRIAN PATHS CUT VERTICALLY ACROSS THE SITE AND ARE FOUND THROUGHOUT THE NEIGHBORHOOD.
Hayden Steps
0' 25' 75' 125' 175'

Site Plan

Parkway and beyond. Stepped pedestrian paths cut vertically across the contours, connecting Lawn Street and Fisher Avenue. These stepped paths are commonly found around the Back of Hill and fascilitate climbing the hills. The topography lends additional character to the housing. The sloping site allows the buildings to be stepped which helps to define individual units and provides increased privacy.

Many attractive elements from the triple-decker vocabulary were incorporated into the site planning. The relationship between each unit and the street is emphasized. Along the site perimeter, units face the public streets. A new street moves through the site to provide a public street orientation for units within the block. Units are accessed directly from these streets to the individual households. As in the adjoining neighborhood, on-street parking occurs adjacent to the units.

The building line is set back from the street by the depth of small front yards. This space accomodates the transition from the public street to the private unit interior. Low fences deliniate the boundaries of semi-private territory. Like tripe-deckers, these

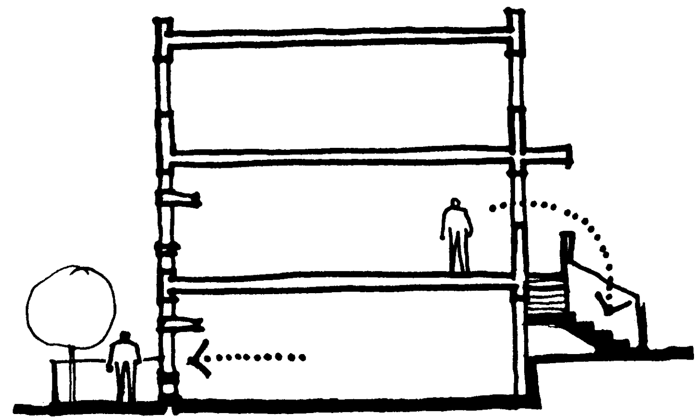
TRIPLE DECKERS with small front yards and frontal orientation units have abutting backyards that are removed from the street and establish the private side of the buildings. The terms "frontyard" and "backyard" are only used figuratively, however, because they are not both used by a single family (except in the townhouses). Upper story residents use the front yards as private outdoor space. Ground level residents have direct access to backyards. Occassionally,

DWELLING ELEVATION along Lawn Street. Units are frontally oriented like Triple Deckers. The sloping site allows the units to be stepped which helps to define the individual units.

this scenario is reversed when the unit access is on the south-side. A small semi-private walkway runs between the backyards for service and egress. Gates at either end restrict its use by the general public.

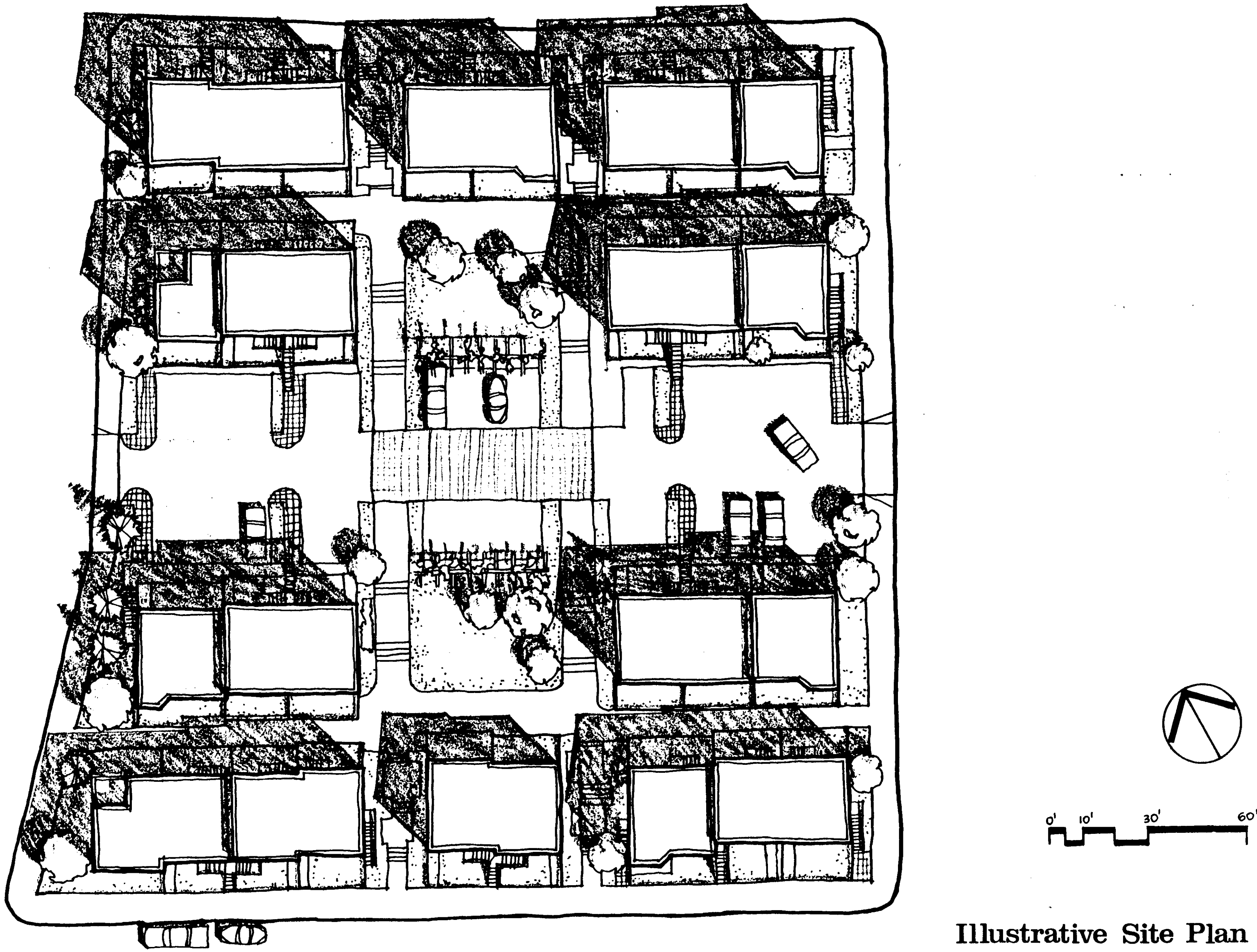
In the center of the block are two semi-public common play areas. These areas are landscaped and are large enough for group activities.

Vegetation is used in a variety of ways to complete the microclimate design. Windbreaks are used in the open spaces between buildings and along the north and west edges of the site. These windbreaks protect pedestrians and the buildings from the cold northwest winter winds. Deciduous trees were planted along the east and west building faces to shade them in the summer. These trees also help to channel the cooling summer breezes along the buildings.

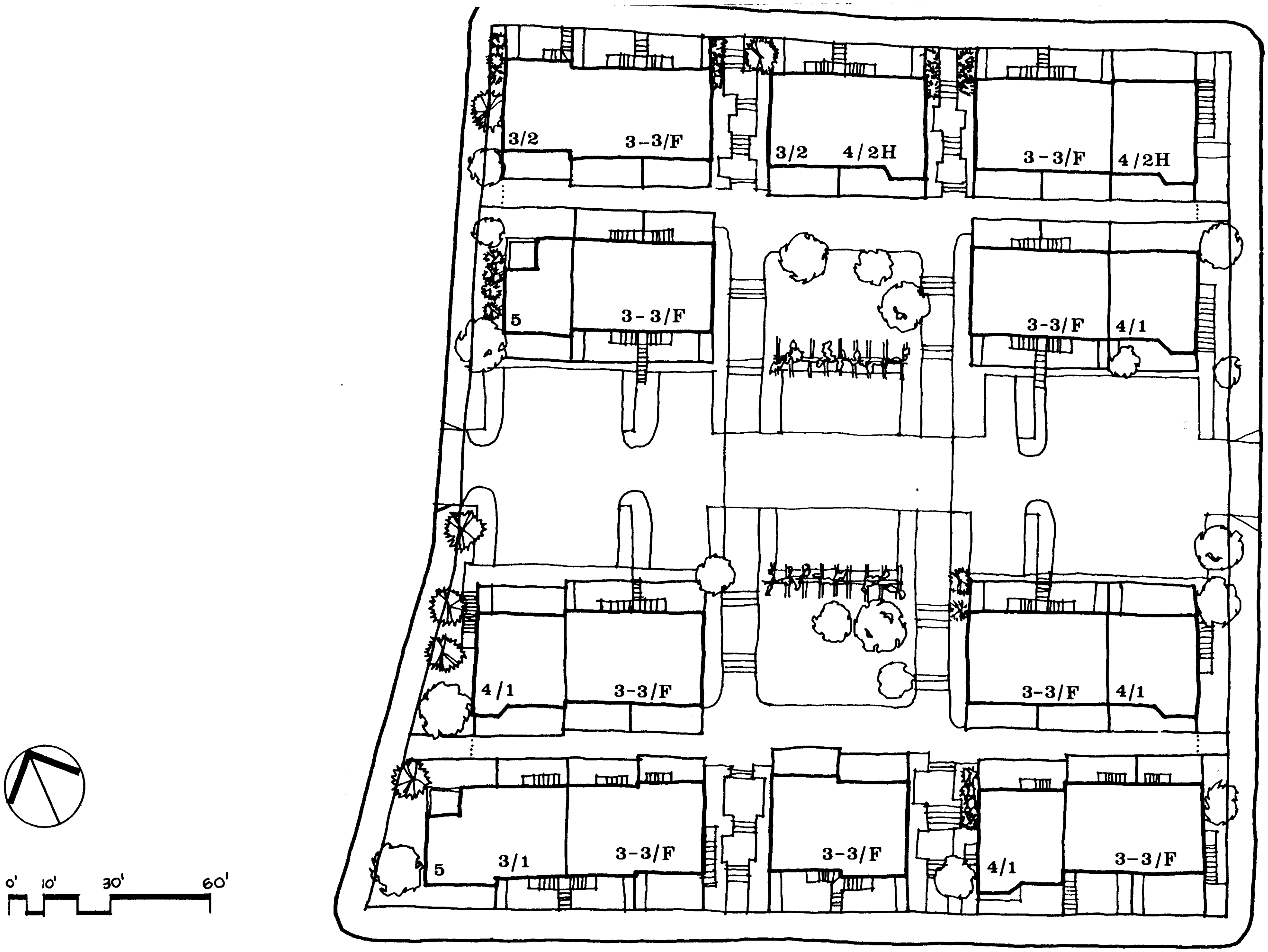


EXAMPLE OF THE FRONTYARD/BACKYARD RELATIONSHIPS. Typically ground level units have backyards and the upper units have the frontyards. Occasionally this scenario is reversed as in the units along Lawn Street.

Perspective Sketch of Boardwalk Scheme



Illustrative Site Plan



Unit Distribution / Breakdown

CHAPTER 4

UNIT DESIGN

Seven different floor plans were generated to meet the variety of projected housing needs. The unit types include one-and three-bedroom flats, two-, three- and four-bedroom duplexes and five-bedroom townhouses. The three-bedroom duplex is the most common unit comprising 64% of the units on the site. This meets the program goal of providing family housing. As shown by the rental calculations, this is the most economical subsidized family unit. It provides ample room for a six-person family and returns a rent easily within the Section 8 fair market limit.

Two references guided the unit design. The existing neighborhood's housing stock of rowhouses and triple deckers are drawn upon repeatedly to establish the contextural relationship. These references are especially appropriate because these building types, as regional urban housing types, have tremendous appeal, flexibility, durability and historical significance. Triple deckers and rowhouses also have the density and scale appropriate for this project.

HUD's Minimum Property Standards for Multi-family housing is the second design

Breakdown of Units

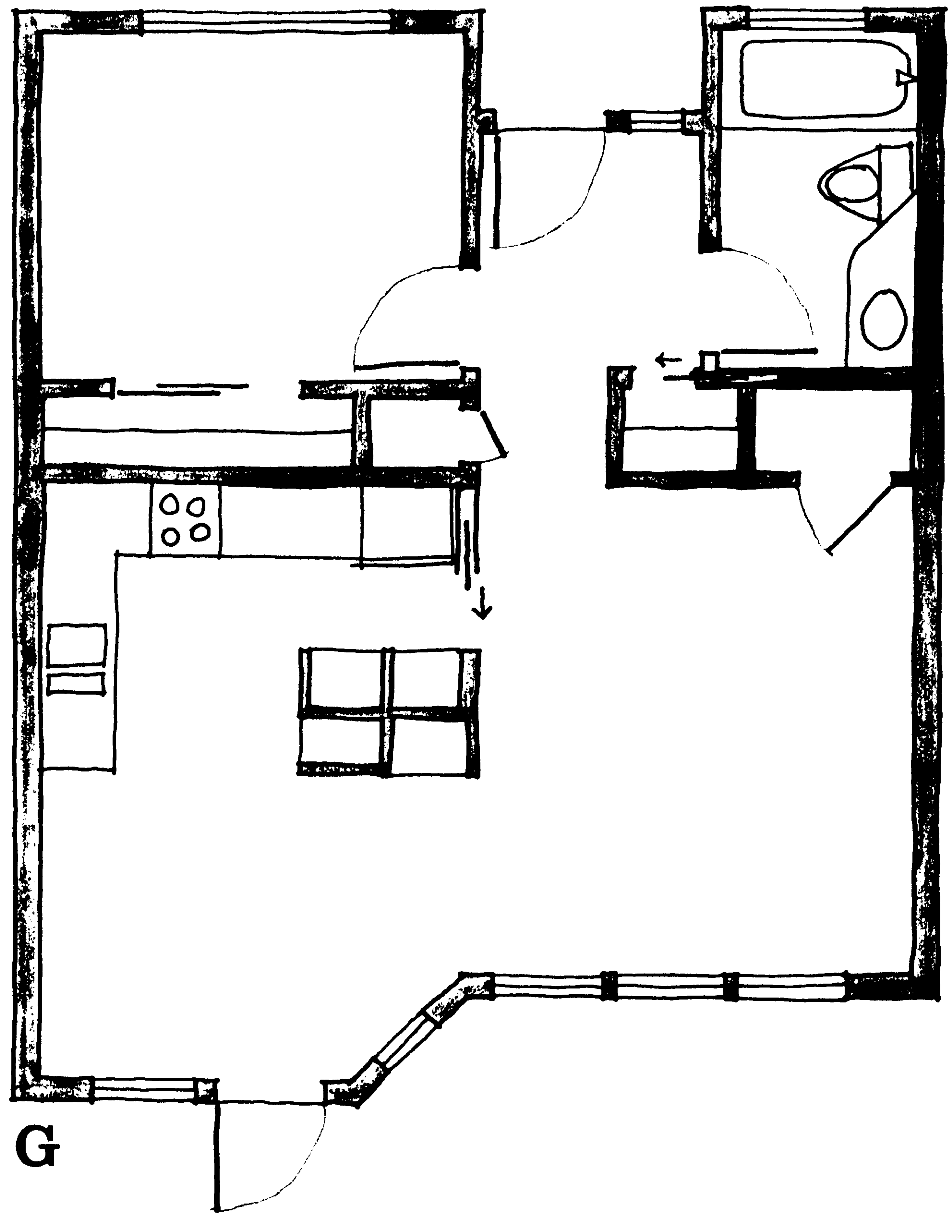
Number of Bedrooms	Number of Units	Percent
1	4	8
2	5*	11
3	30	64
4	6	13
5	2	4
Total	47	

* includes 2 handicapped units

reference. Similar to a building code, the Minimum Property Standards (MPS) outline the least acceptable building specifications in terms of functional dimensions and material qualities. Unfortunately, these specifications are far too often unimaginatively translated into the least acceptable dwelling when applied to subsidized housing. The public housing projects of the 1930's and 40's are prime examples of this practice. The problem has been avoided here by using the MPS as mere touchstones in the design process.

A mix of family sizes is encouraged by the combination of small and large family units in a single building. Duplexes are typically arranged over flats to produce 3 to 3 1/2 story buildings. Some three-bedroom units have been designed as flats with two three-bedroom duplexes above. This combination is a very successful design solution.

The "duplex-over-flat" configuration provides on-grade entries for handicapped or elderly residents and a short ascent to second level entries. A single stair is shared by two upper level units. These outside steps offer residents an informal place to congregate



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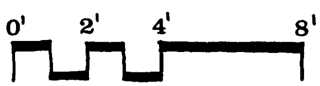
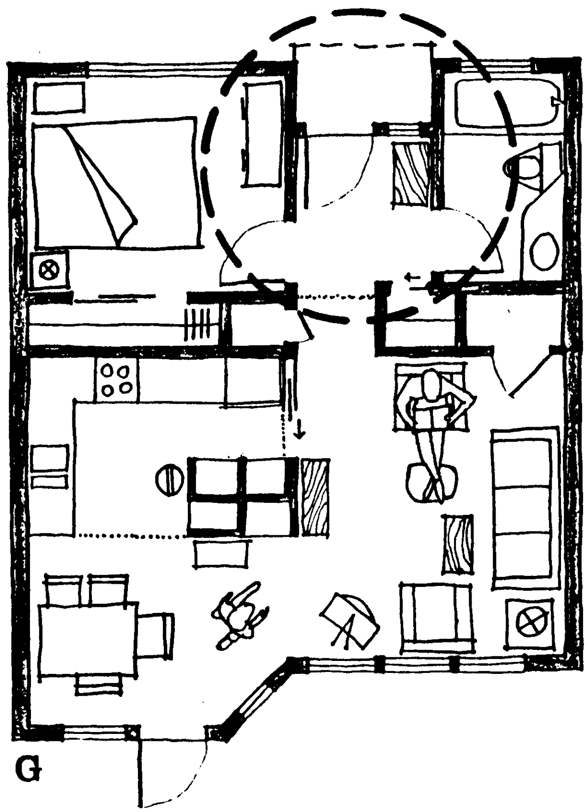


One Bedroom Unit



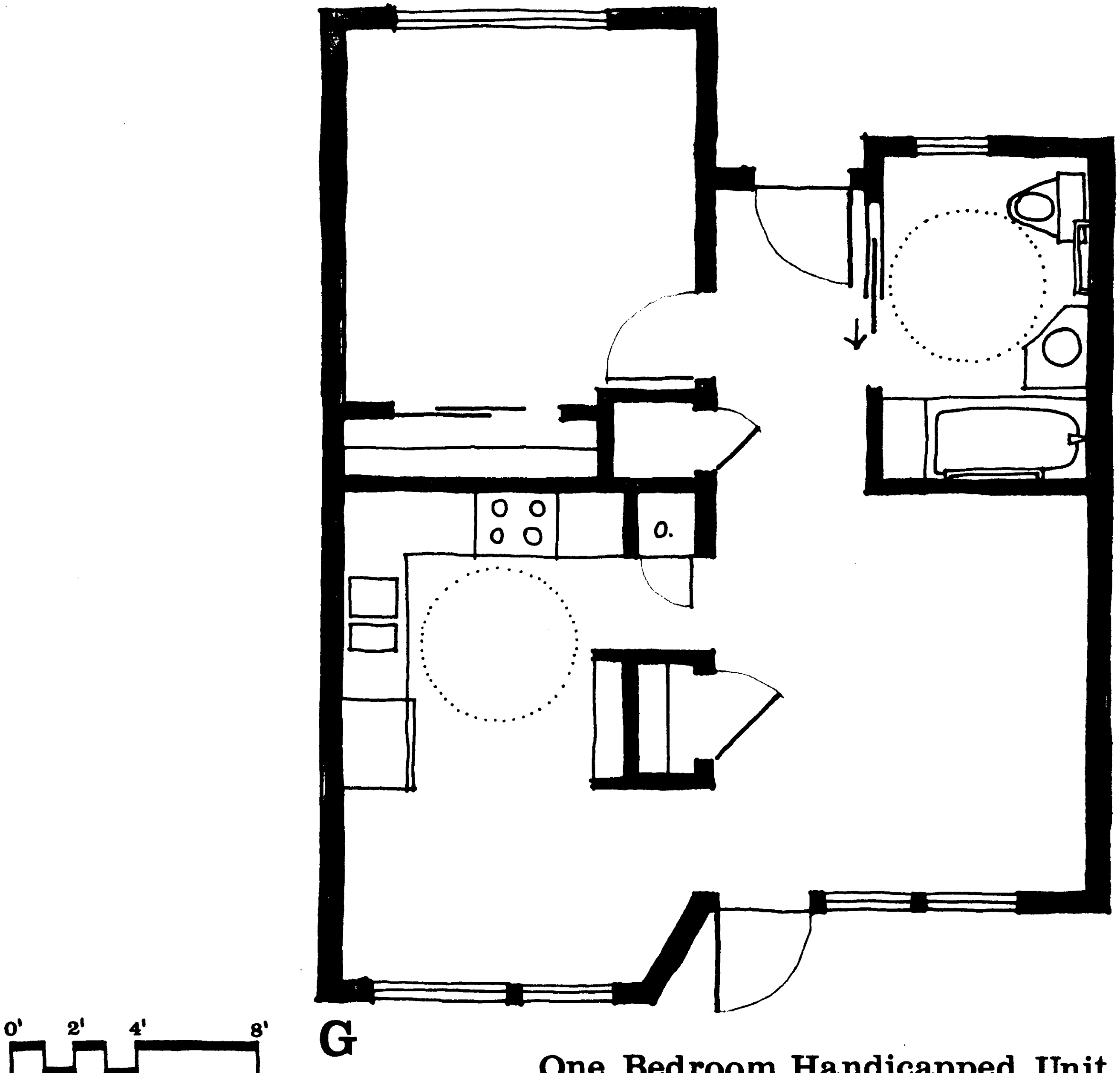
THE INDENTED ENTRY helps to shorten the interior circulation space. The overhang provides protection from the weather. The wide hallway allows furniture placement.

while discouraging their use by outsiders. The territory established by steps and fences provides natural security. Also, residents have a direct line of sight to their front doors from the street. Besides the safety benefit, people derive satisfaction from being able to see and identify their units.

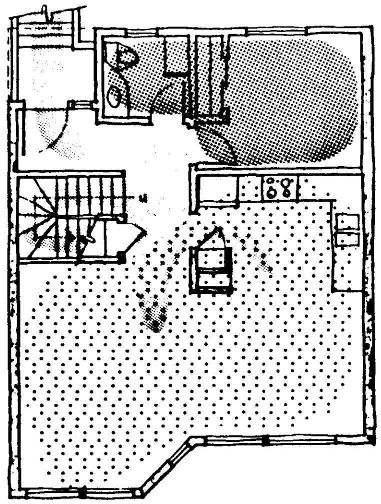
The unit interiors are designed to function efficiently and offer the occupants a great degree of freedom and enjoyment.

By grouping spaces around a central core, interior circulation is minimized to provide the most usable floor area. As in rowhouses, the core includes the stairs and hallways. Unit entries are given definition and the protection of the building overhang by being indented. This also helps to shorten the hallways. Many units have hallways wide enough to accomodate the placement of furniture making them more than circulation space. A table or shelves could be placed in the entry of the one- or two-bedroom units.

In all the units, quiet and active zones are established. This zoning allows people to conduct a variety of activities simultaneously.



One Bedroom Handicapped Unit



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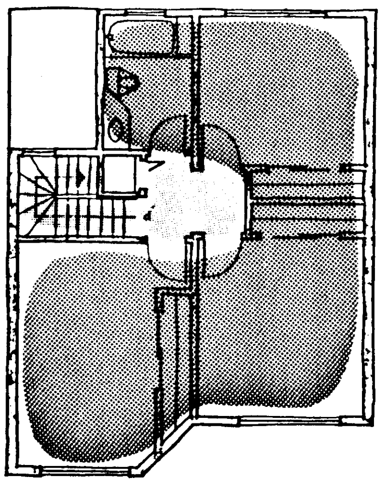


3 Four Bedroom Unit

Public

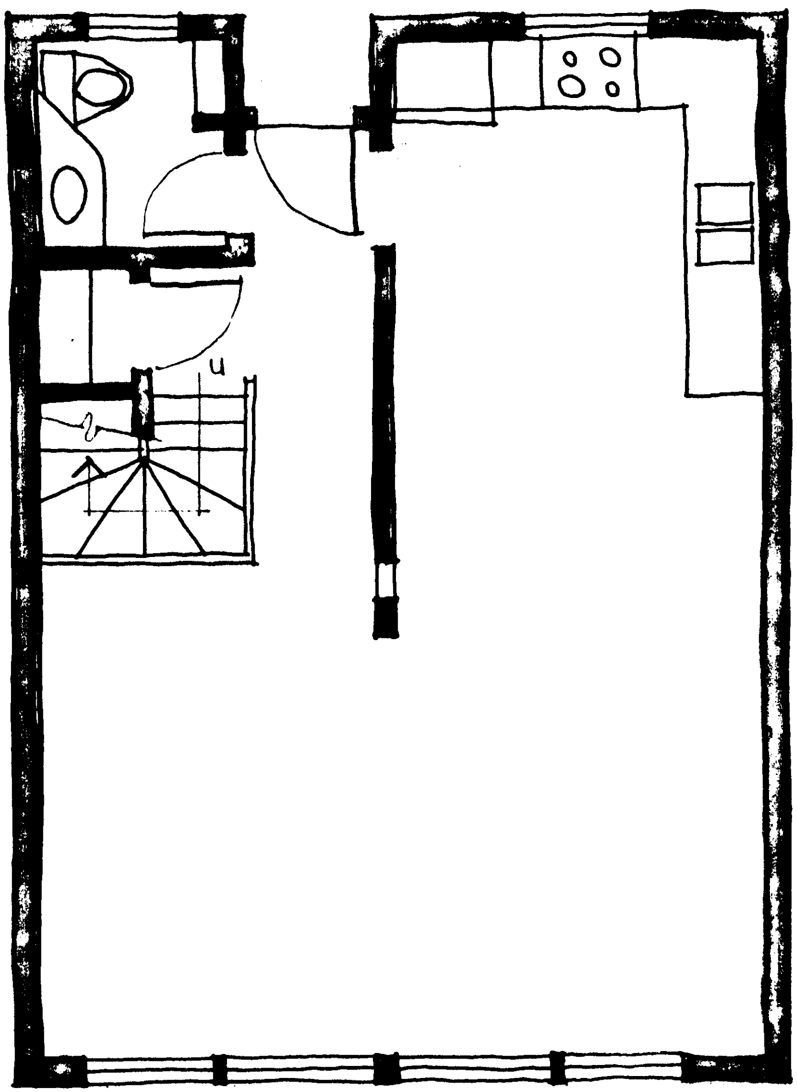
Private

Circulation

PUBLIC/PRIVATE SEPARATION is maximized in two-story units.

Two-story units allow the greatest separation of these functions. First level entries take residents directly into the public spaces. Kitchens are conveniently located close to the front door for dropping off groceries or receiving children after playing outside. Bed-rooms, the quiet zones, are located on the second level and can be reached without passing through other rooms. This arrangment allows the floor materials to be zoned; kitchens and entries can be finished with a durable washable material, while the living room and second level can be carpeted.

Generously-sized living rooms accomodate a broad range of family activities and furniture groupings. Except for the glazed south face, the living rooms have expansive blank walls for hanging pictures or furniture placement. Users achieve optimum flexibility for adapting their environment to suit their needs. The same design features are found in the bedrooms which are larger than recommended by the MPS. The smallest room dimension allows a dresser to be placed at the foot of a bed. The fenestration in the bedrooms has been carefully planned so that numerous arrangements of beds, nightstands,



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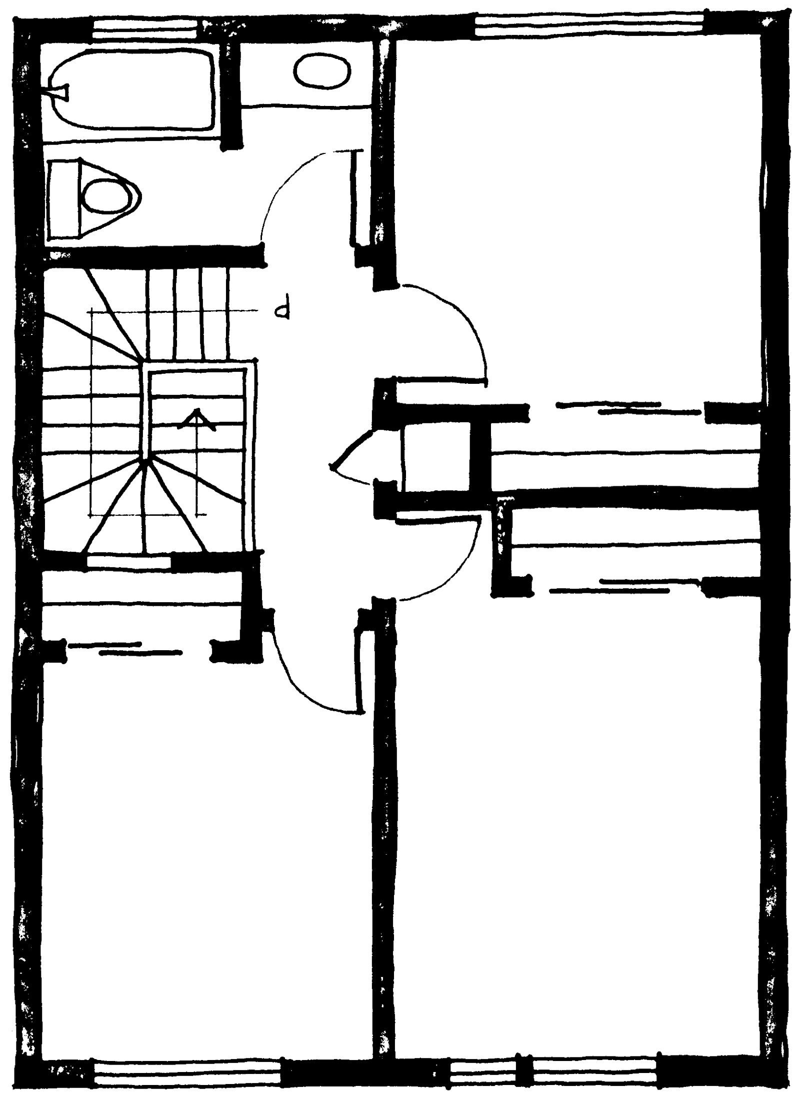

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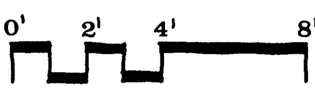
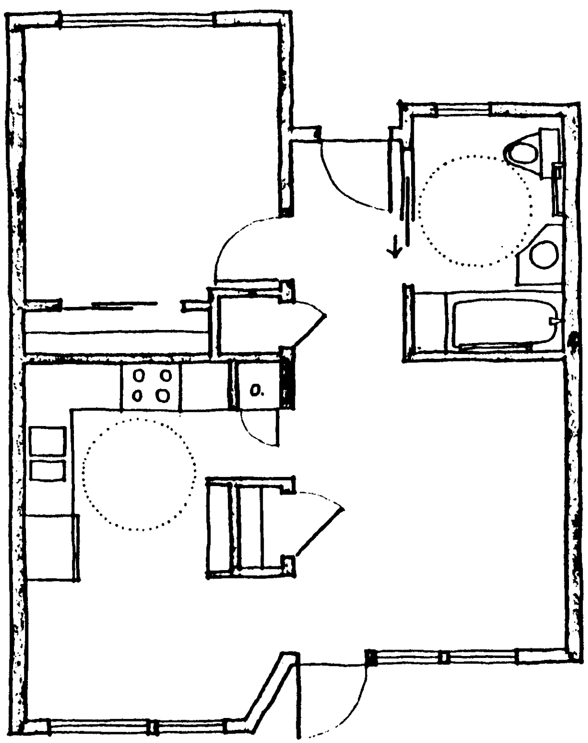


Three Bedroom Unit

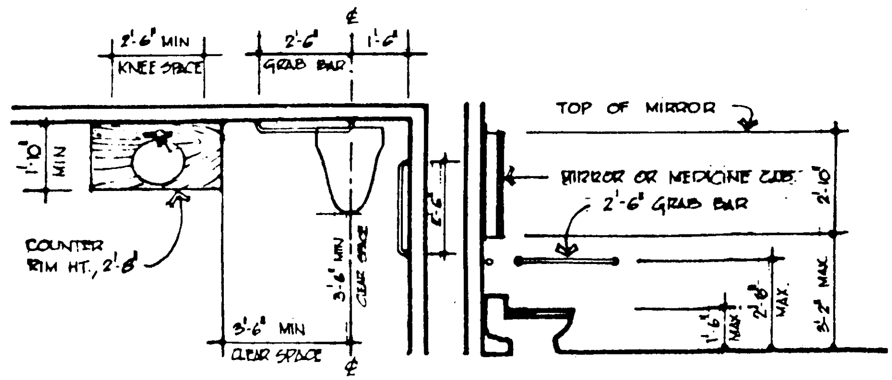
Special design considerations for the handicapped units come from the Massachusetts State Handicapped Code. Doorways, hallways and rooms are all large enough to allow persons in wheelchairs easy access. The important changes are in the kitchens and bathrooms where a five foot diameter clear space is required for wheelchair maneuvering. Bathrooms are fitted with grab bars and a tub with a seat. All the required clearances are met. In the kitchen, cooktops, sinks and preparation areas have knee space under the counters. A wall oven replaces the under-range oven.

Entries to handicapped units are ramped and often use the sloping topography to provide level access.

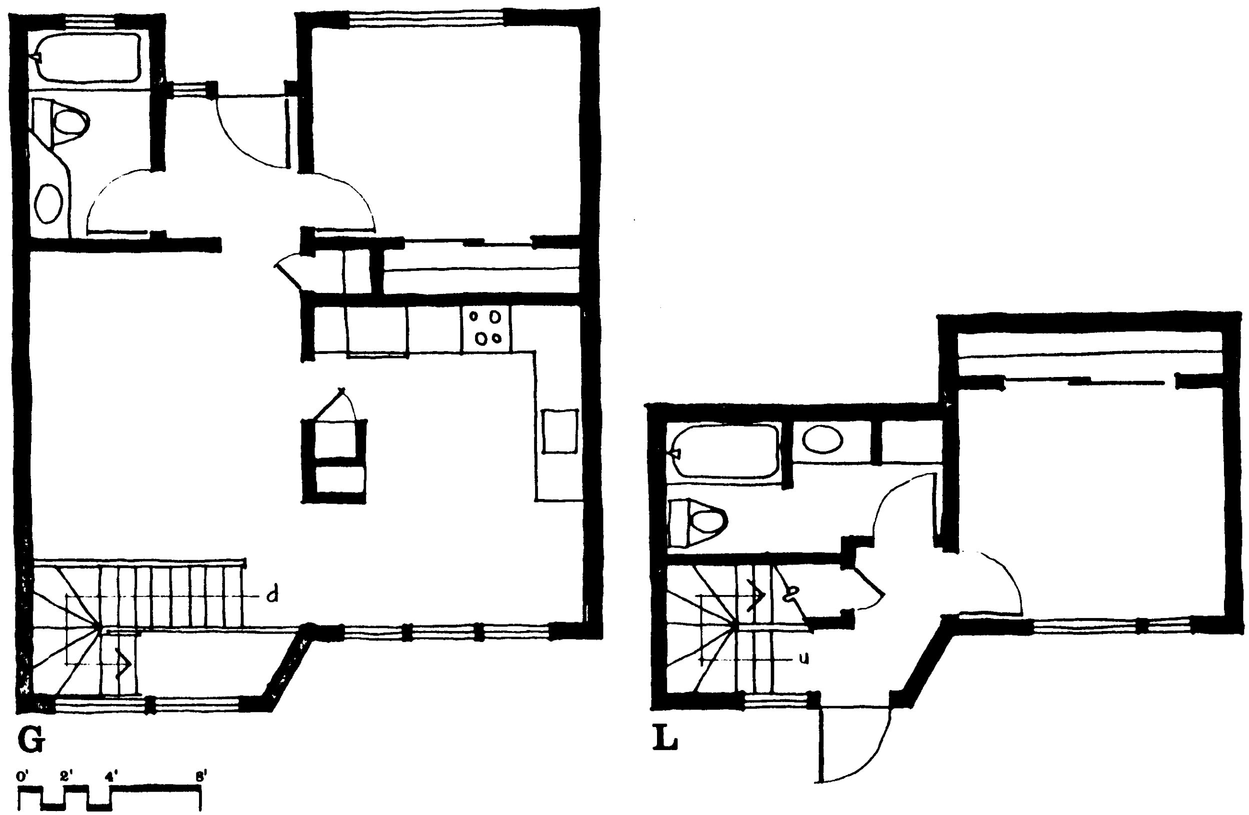


G **One Bedroom Handicapped Unit**

IN KITCHENS AND BATHROOMS of the handicapped units, a 5'-0" diameter circle of clear space is required for wheelchair maneuvering. Beside, the minimum dimension requirements for handicapped bathrooms are shown. Source: Massachusetts Handicapped Code.



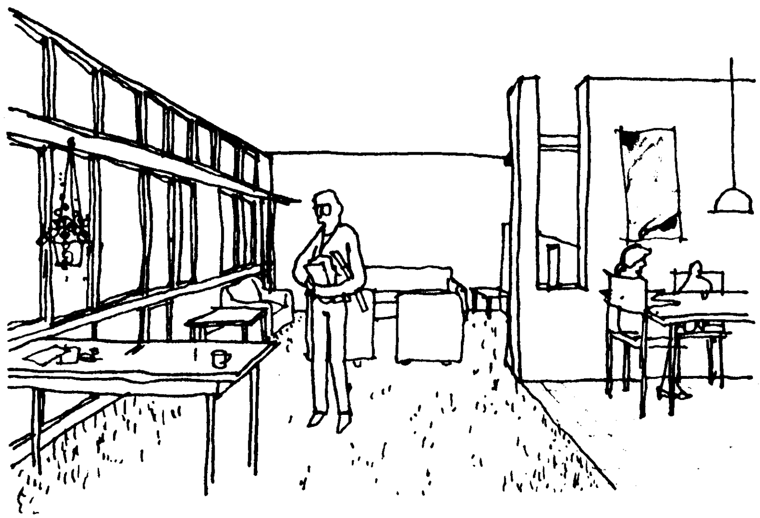
PLAN **SECTION**



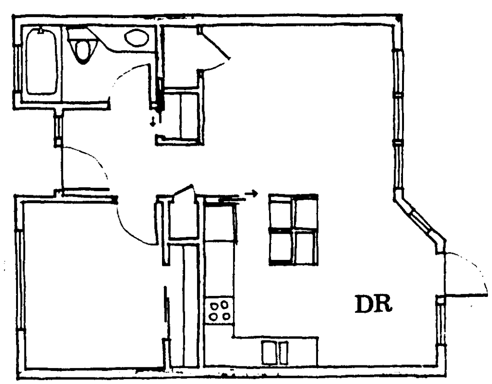
Two Bedroom Unit

chairs and bureaus can be facilitated without obstructing the windows.

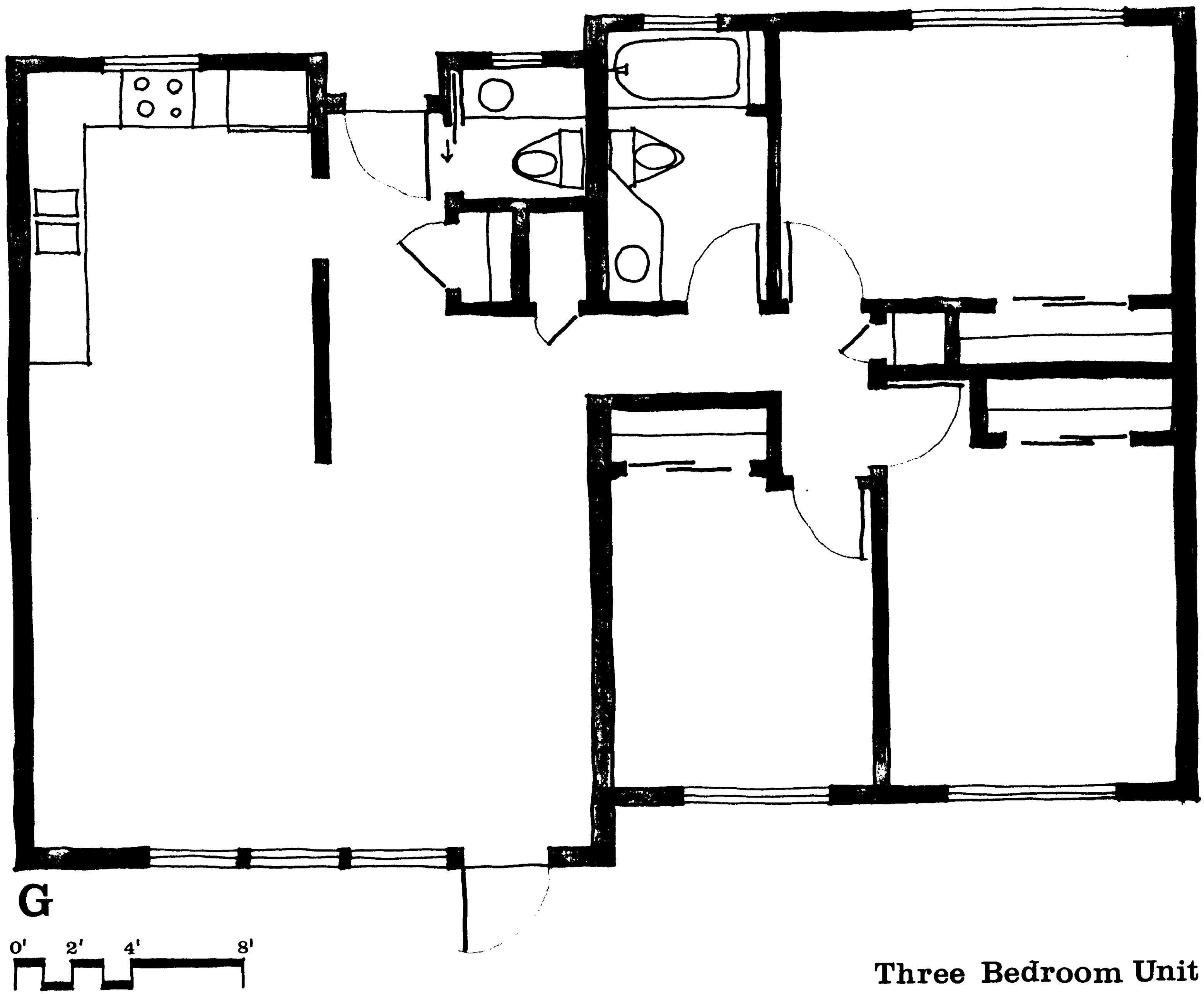
Wherever possible, open space planning is used to increase the number of possible views and sense of spaciousness through space borrowing. Living rooms, kitchens and dining rooms are visually, and often physically, connected. Partial walls, counters, storage units and floor materials are used architecturally to distinguish these various rooms. Dining areas are located in the kitchens because users interviewed preferred this arrangement over living-dining rooms. One-bedroom units vary from this pattern; the dining area is projected from the kitchen to form a sort of bay which draws upon the triple decker/ rowhouse vocabulary.



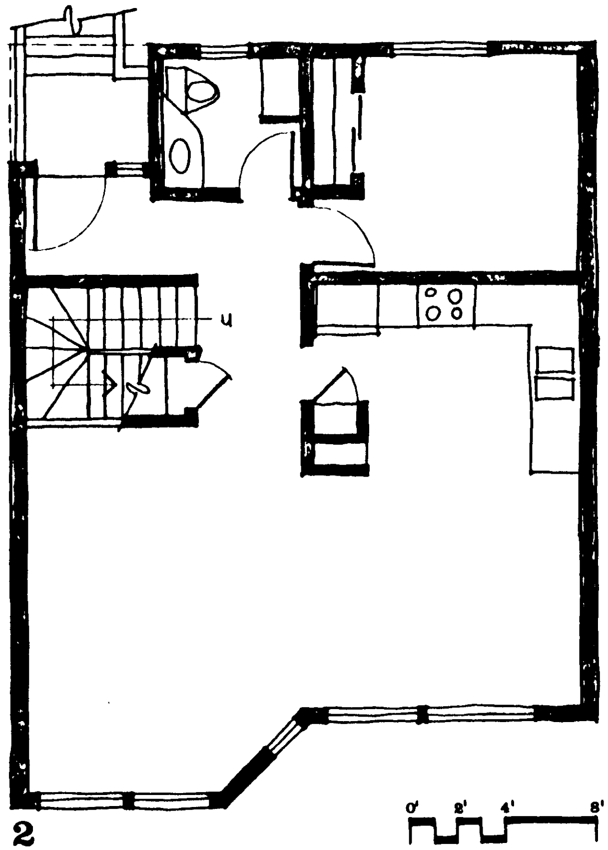
SPACE BORROWING is achieved by making the most number of spaces visually accessible at once. Units appear larger, roomier, with spaces flowing together in an open plan.



DINING AREA becomes a projected bay window in the one-bedroom unit.



Three Bedroom Unit



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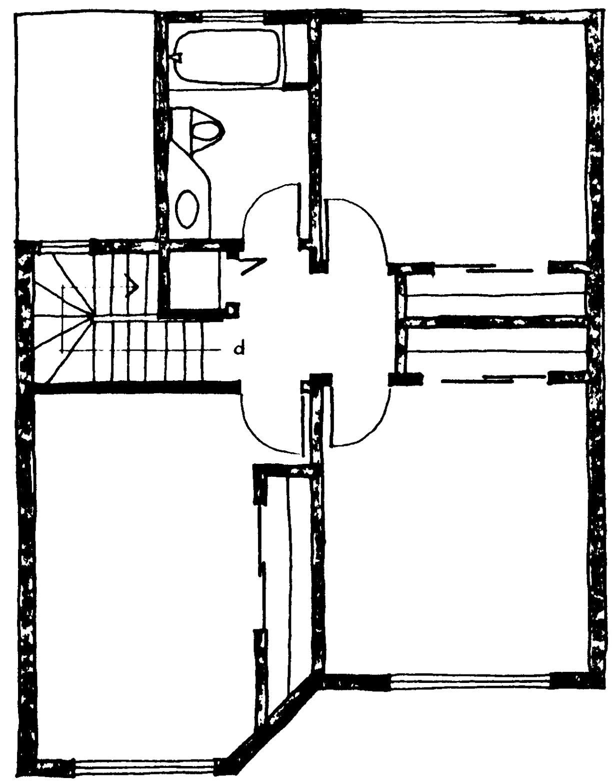

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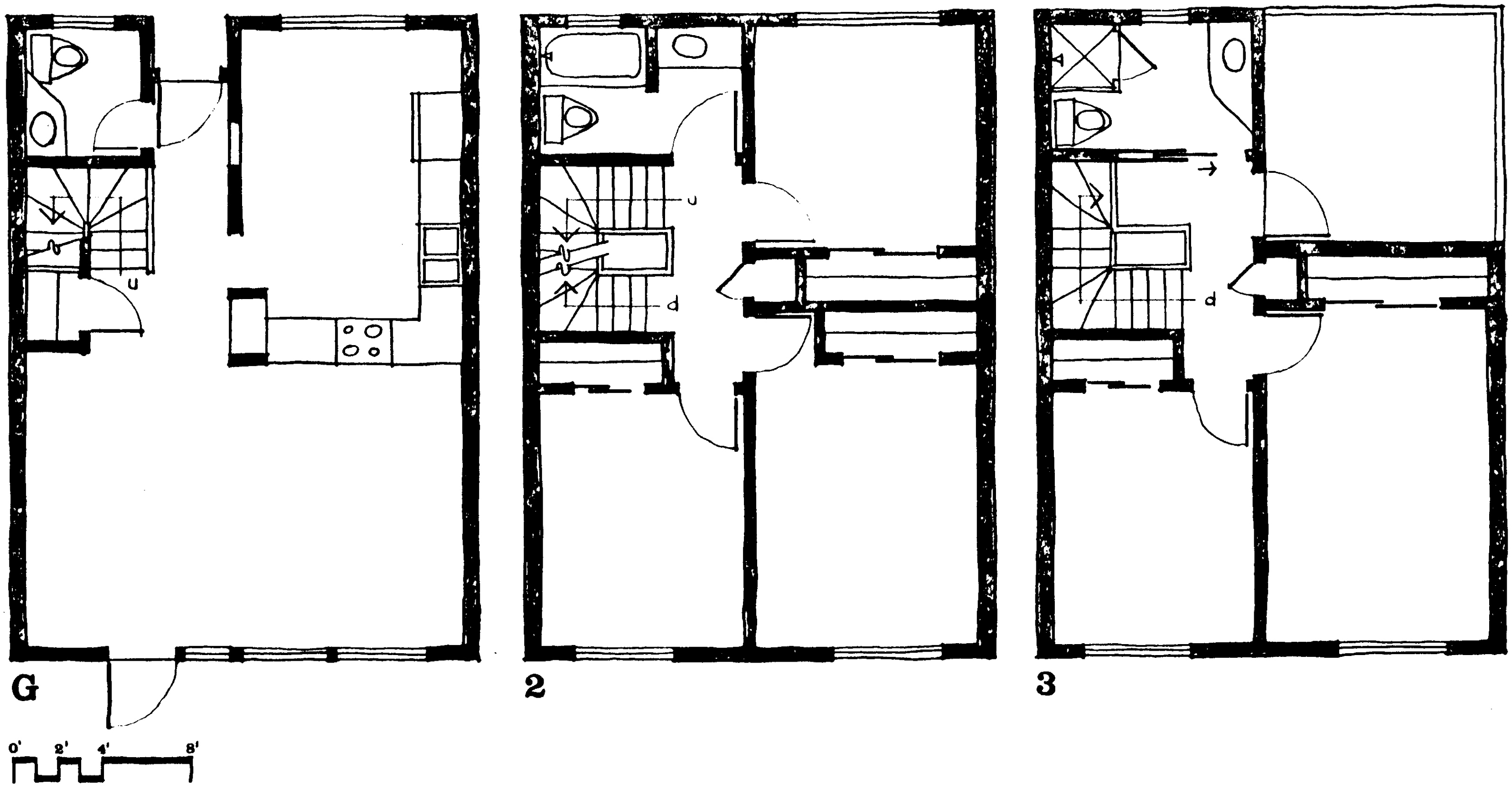
Four Bedroom Unit



Five Bedroom Townhouse

NATURAL ENVIRONMENTAL SPACE TEMPERING IN LOW-INCOME SUBSIDIZED HOUSING

Low-income families pay a greater percent of their available income for utilities than do middle-income people.[4] Here in the northeast where expensive fuel oil is used, the majority of this utility expenditure is for home heating. Thus, low-income people are most adversely impacted by spiralling fuel prices and energy politics. Add to this the fact that 30% of all low-income people in the U.S. live in the northern urban areas and rent their homes.[5]

Typically in a rental situation the occupant has no control of the heating. An inefficient centralized system supplies heat to individual units and the total heating bill is divided indiscriminately among the tenants. This encourages wasteful consumption and does not reward conservation. The use of passive solar energy for home heating is an immediate and economical means of alleviating this situation.

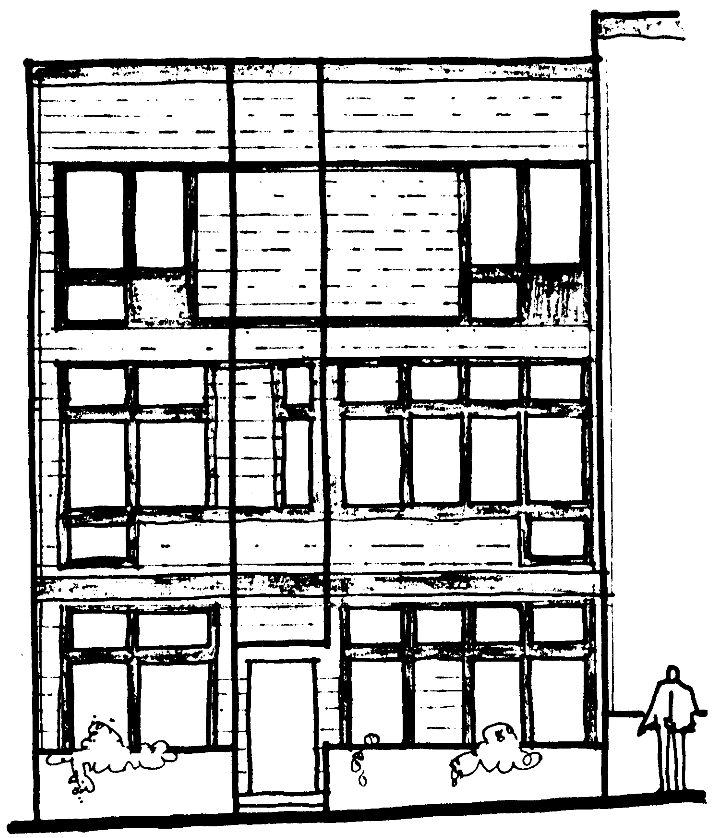
The beauty of passive solar technologies is that the end use energy is matched to the collection form. A passive system derives the greatest benefit from the natural forces of the sun and the natural properties of the building configuration and materials. This simplicity of concept (and design) yeilds several benefits. In residential applications, appropriate technology solutions can be developed which lower the overall energy consumption. Costly and inefficient conversion of energy is eliminated. Because the building itself is the system, with the building materials collecting, storing and later reradiating energy, passive solar heating can cost little or nothing. Operating the system is absolutely free and requires minimal user maintenance or participation. These merits make passive solar heating a very attractive answer to the energy needs of low-income people.

CHOOSING THE TYPE OF SYSTEM

Two methods of passive solar heating are available--direct and indirect gain. Both of these types have the two basic components of collector and thermal mass.

Direct gain is the most simple passive solar heating system. Large areas of south-facing windows are employed as the solar collectors. The thermal mass is located

SOLAR COLLECTING SOUTH WINDOWS



throughout the unit interior to absorb and store the collected heat. During the winter months, the sun shines right into the living spaces, heating them directly.

The second passive method of solar heating, indirect gain, combines the collector and thermal mass. Solar radiation passing through the glass is intercepted by the thermal mass and never enters the living spaces. Then, the energy stored in the mass is transferred as heat to the interior spaces.

For this design, the direct gain approach was chosen. The choice was made easy by two of its advantages over indirect gain. First, the direct gain system offers the most architectual flexibility in multi-family housing where the exterior exposure is usually limited to a single wall. A thermal mass blocking this wall would obsure views and make access and ventilation difficult. Second, direct gain systems are potentially twice as efficient as indirect ones.

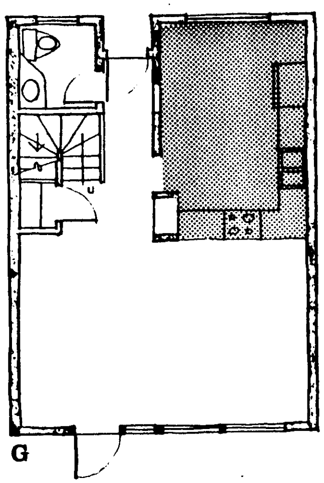
THE DIRECT GAIN DESIGN

The clear south windows admit solar gain in the winter when it is needed for heating.

Sufficient thermal mass is provided to maintain a comfortable indoor air temperature and retain thermal energy for cold nights and cloudy days. During the summer, when heat gain is undesirable the south-facing glass is shaded. With the sun's altitude high, small overhangs or other simple devices can be used to eliminate direct sunlight penetration.

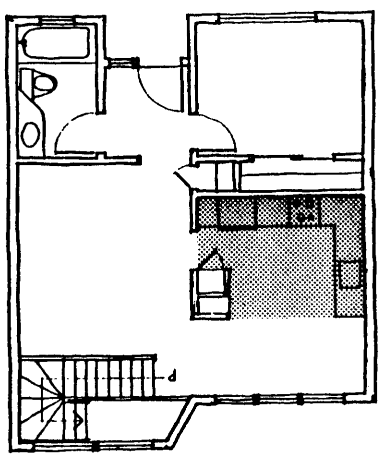
Prevention of overheating is one of the most critical criterion for a direct gain design. As mentioned above, the thermal mass is responsible for the indoor comfort because it limits the daily temperature swing. The majority of the solar intake occurs between 8 a.m. and 4 p.m. While the peak heating demand is at night or on cloudy days.

When conventional building materials are used as thermal mass, sunlight must be dispersed throughout the interior spaces. The general rule of thumb for sizing such distributed mass is five times the area of south-facing glass. The use of common building materials is quite attractive in this particular housing application because they are the least expensive. Local labor, standard construction method and prefabrication also keep the system cost low.



G

Five Bedroom Townhouse



G

Two Bedroom Unit

HIGH INTERNAL GAIN SPACES
shown in two units

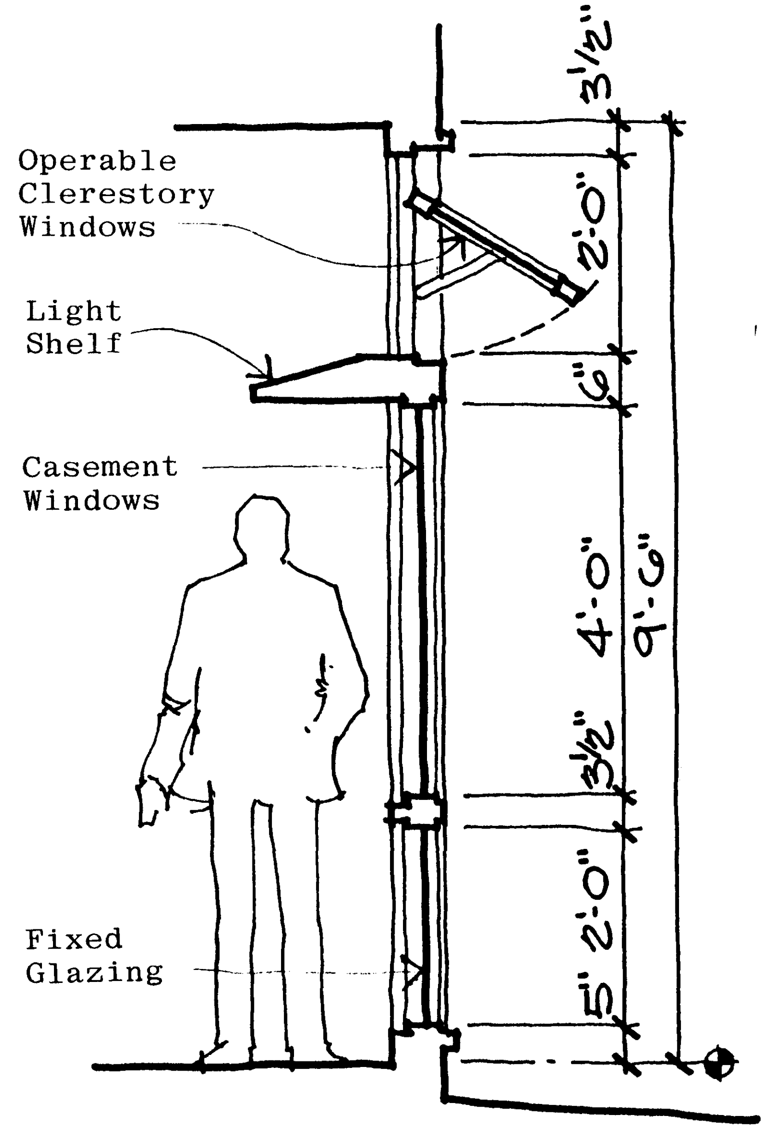
The architectural response for the direct gain system addresses overheating, thermal mass provision, thermal comfort, energy distribution, cost and energy conservation.

Thoughtful space planning can lower the heating load making the most efficient use of the solar energy collected. Using groupings aid in this respect to overcome the displacement of non-direct gain spaces. Small rooms requiring minimal heating form a buffer zone on the north side of the units. These spaces include bathrooms and storage closets. Kitchens are also located in the buffer zone; the high internal gains supplied by kitchen appliances and occupants are enough to heat this space. Aggregating the smaller spaces on the north side liberates the south side for large living spaces. Thus, bedrooms and living rooms are warmed directly by the sun. This arrangement allows the incoming sunlight to strike large areas of thermal mass.

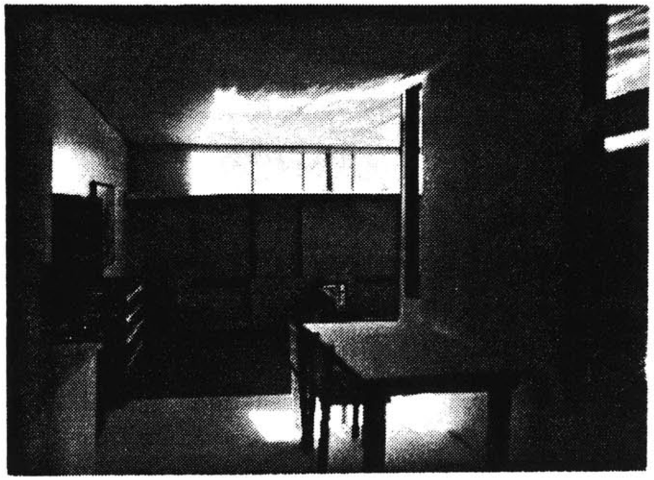
Bedrooms that face north employ a unique method for obtaining a portion of their heat from diffuse and reflected sunlight. North-facing windows use a special double glazing combination of clear glass and a pane treated with a heat mirror coating. Heat mirror is transparent to incoming shortwave radiation but reflects long wave radiation back into the rooms. Thus, energy from diffuse sunlight and internal gains is trapped to heat these rooms.

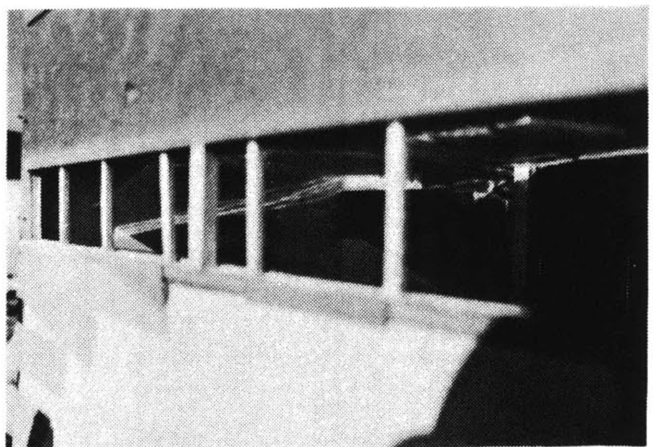
In each space receiving direct radiation, the proportion of solar collecting, south-facing glazing to heated floor area is approximately 17%. This window area stays within the 5 to 1 mass-to-glass ratio so that the indoor air temperature is maintained below 72°F throughout the unit.

The raised ceiling height easily accomodates this large glass area and still provides floor to ceiling wall space on the south wall for furniture. Three horizontal bands of differing window types provide various functions. The topmost band is a clerestory extending nearly the entire width of the south wall. Four-foot high casement windows compose the center band. Views are attained though these windows. Below them, in the lowest band are several windows that reach from the floor to the average desk height of 30". Each band contains fixed operable lites. In the bed-



Section of South Window Wall





THE LIGHT SHELF directs incoming sunlight onto the ceiling making it a large light source.

rooms, window openings typically occur below the seven foot door height. Only in the north-facing bedrooms where a large glass area is needed do these windows reach above this height. Later in the chapter, the natural daylighting and ventilation design features of the south window wall are described.

The clerestory windows combined with a reflectorized light shelf to direct sunlight to the mass far from the south windows. Winter sun angles were used to design the light shelf. A slight cant is added to the shelf to increase the depth of light pentration. The width and cant of the light shelf carefully project light to the ceiling and walls above head height. This keeps bright reflections out of people's eyes. When energy, in the form of sunlight is thrown deep into the rooms its diffusion through multiple bounces can be achieved. With each successive bounce, more energy is absorbed by the building's mass.

Choosing a Strorage Medium

Wood framed construction is the most economical and common building system for housing of this scale. Initially, it alone was considered for this design. However, wood framing employs lightweight materials with low effective heat capabilities. Several methods were explored for adding mass to the unit interiors.

The ceilings, floor, party walls and even interior partition walls offer potential storage in a direct gain system. For application in an all wood-framed home, two storage options were selected:

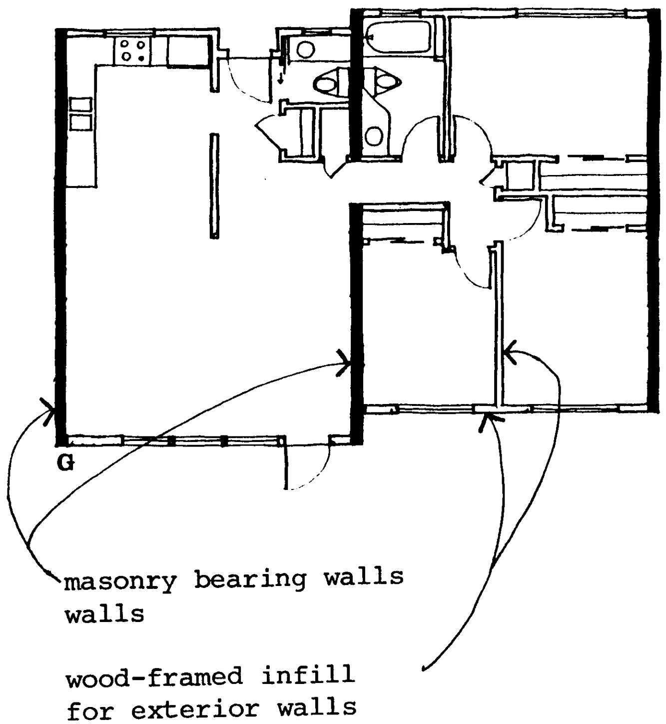
1) Thermal storage bags
2) High density wallboard (cement asbestos board or Wonderboard)

The thermal storage bags contain a phase change material to store heat latently. The chemical storage medium changes its physical state as it absorbs heat energy rather than becoming hotter. In this application the bags rest immediately above the finished ceiling where the light shelf directs incoming beam radiation. Heat transfer through the ceiling is enhanced by choosing a highly conductive finish material (fire-rated gypsum board or metal pans). The ceiling is painted a relatively dark, non-reflective color to absorb light. Electrical resistant mats are placed over the bags to do off-peak electric heating.

The second alternative replaces the typical double layer of gypsum board used in the party wall construction. Two layers of 5/8" Wonder-board or similar wallboard are used instead for their increased thermal capacity.

Both these options for thermal mass prove to be quite effective for heat storage and temperature regulation. The average indoor air temperature is 73°F on a clear March day if cement asbestos wallboard is used. However, when the cost of these materials was calculated, as shown in the comparitive cost section of Chapter 5, both were far too expensive to be considered for this design. Any saving going in the energy budget would have been entirely consumed to pay for the storage medium alone. Therefore a less expensive storage medium was sought.

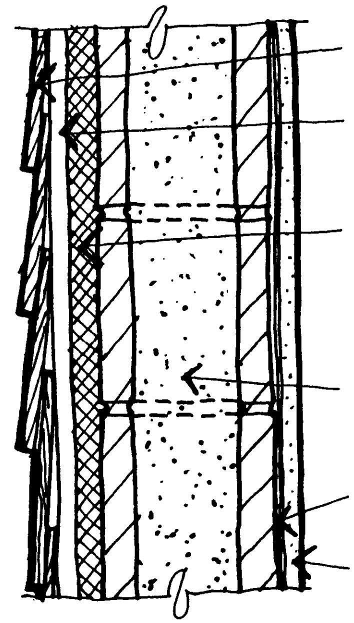
By using a hybrid construction system of concrete block and wood framing an affordable alternative was developed. Masonry is one of



the most popular building materials used for thermal mass. Eight-inch concrete block walls become the party wall/fire separations between units and the weather and partition walls are wood framed.

This concrete block party wall detail adds 26¢ per square foot of wall area to the cost of construction. The concrete block storage helps to maintain an average indoor-temperature of 64°F + 8°F on a clear day in March.

Wood siding is applied over the concrete block on the east and west walls of the grouped units. This makes the application of insulation simple and projects the image of the wood-framed triple deckers.

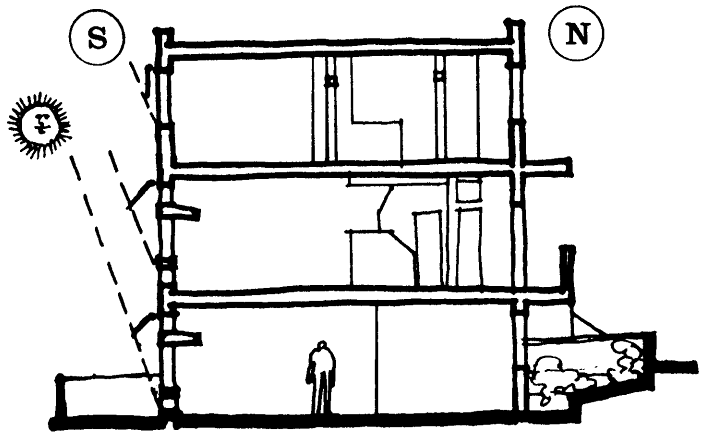


Concrete Block End Wall Construction

Sun Control

A passive solar heating system often employs several techniques for controlling the amount and type of sun being admitted. The light manipulation is done by the building components.

Summer sun control means keeping the solar gain small while maintaing light and views. Since the south face of the buildings have no overhangs, awnings have been introduced. These light colored canvas awnings are placed above



EXTERIOR SHADING DEVICE
A canvas awning is rolled down in the summer to shade the light shelf from direct sunlight.

the clerestory windows. From May to October the awnings are extended to shade the clerestory windows and the light shelf from direct sun. Because the canvas is a light color, translucent light filters through, illuminating the unit. The view windows below the light shelf are shaded by the shadow cast from the awnings. Views from the living spaces remain unobstructed.

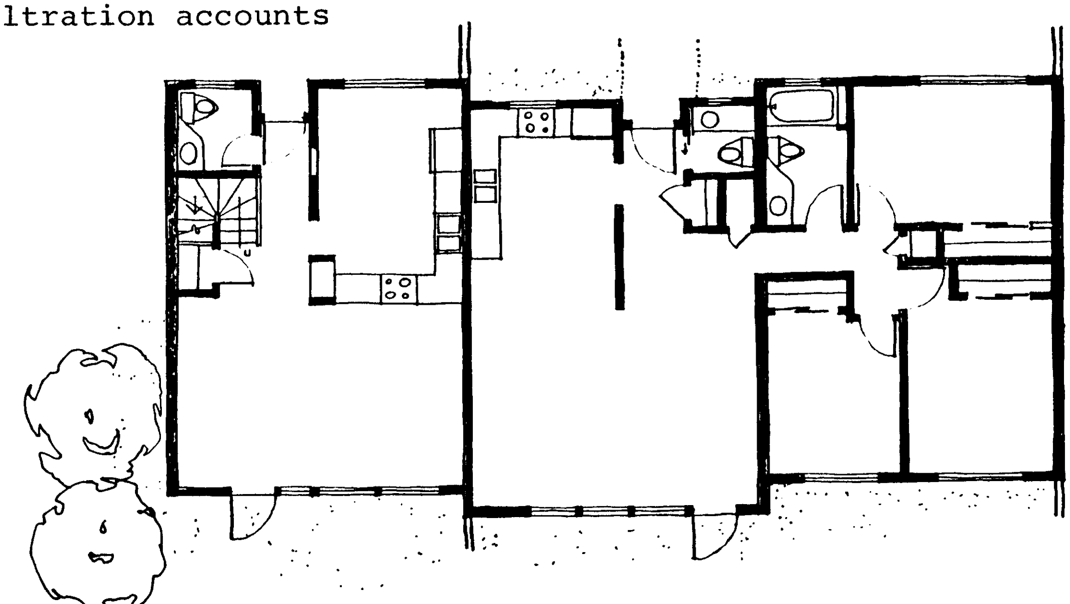
Using an exterior shading device keeps the glass cool reducing this type of solar gain. Interior window dressing used during the day hamper views to the outdoors and do nothing to reduce the heat gain due to sun shining on the window glazing.

The control of glare is an important design consideration that is discussed in the daylighting section.

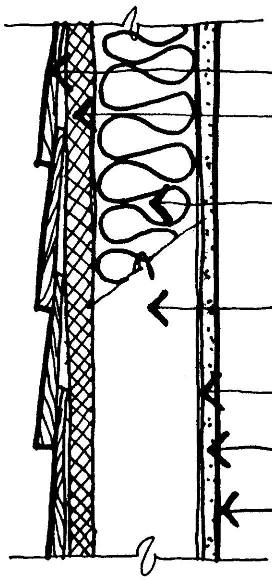
Conservation

It has been estimated that homes built today, with new technologies and energy conscious design, can save 50% of the energy consumed by homes built as recently as 1975.[6] Energy conservation plays a major role in the effectiveness of the solar system designed here. Conservation of energy lowers the heating load so that the solar heating has the greatest impact. Ultimately, this lessens the auxiliary heating needs and saves money. Many improved, energy conscious construction methods that cost little or nothing are implemented in this housing design.

Attaching the units like rowhouses reduces the exposed wall area thereby lessening the conduction heat losses through the building skin. Air leaks in the building envelope produce the greatest heat loss. Tight construction including careful caulking and weather-stripping is necessary to minimize air infiltration. In this housing, infiltration accounts



ATTACHED UNITS,
Reminicent of rowhouses save energy



Exterior Wood-Framed Wall Construction

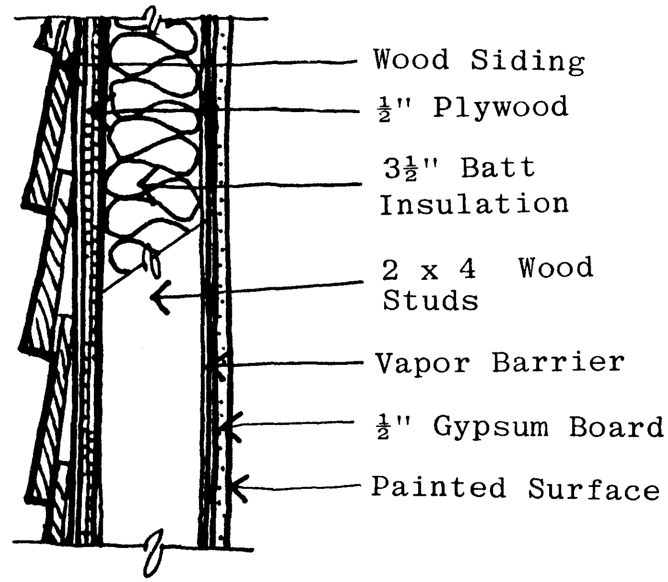
for a little less than 50% of the building losses. Residents may wish to enclose their covered front entries to create air locks and further reduct infiltration. Double-glazed southern windows curb the tremendous heat loss through the windows. The aforementioned heat mirrored glazing in the north-facing windows aids in energy conservation.

An energy saving alternative is used for the sheating material; instead of plywood, styrofoam is used. Styrofoam is an extruded polystyrene product whose tongue and groove design makes for a tight seal between the individual 2'x8' sheets. This cuts infiltration. Its advantages are a high R-value, R-5.41 and low cost. Styrofoam is one half the price of plywood. This saving goes into the solar budget. In a standard wall construction, uninsulated studs are in contact with the exterior sheathing and contribute 20% of the heat loss through the walls.[7] A thermal break is achieved by placing Styrofoam under the siding and the heat loss through the framing is mitigated. This rigid insulation is used in conjunction with 3 1/2" batt insulation. Since it has no structural properties, lateral stability is given by 1"x4" let-in bracing.

Appendix 3a compares the R-values for the wall construction used in this design to a typical wall meeting MPS specifications. The use of styrofoam produces an R-17 wall.

Because the ceiling area is large and heat rises, heat loss through the roof and attic spaces contribute appreciably to the total building losses. Roof insulation is enhanced by the addition of the styrofoam insulation and thicker batt insulation to yield an R-30 rating.

The natural slope of the land allows earth berming around many of the ground level units. Berming helps to retain building heat for in winter the ground is warmer than the outdoor air temperature.



Typical MPS Construction

NATURAL DAYLIGHTING

The considerations for solar heating and natural daylighting are closely related; they both rely on the character and quantity of sunlight entering the dwelling. Many of the design responses and building components of the passive solar heating system also fascilitate good natural daylighting.

In residential architecture there is no need to justify the use of natural daylighting;

it is a given. A certain area of windows for light and air are even required by code. For a passively heated home using direct gain, designing for the most effective daylighting is more the concern.

The criteria for natural daylighting design include optimizing the use of daylight providing well-distributed daylight and ensuring visual comfort. These goals work to the advantage of solar heating as well.

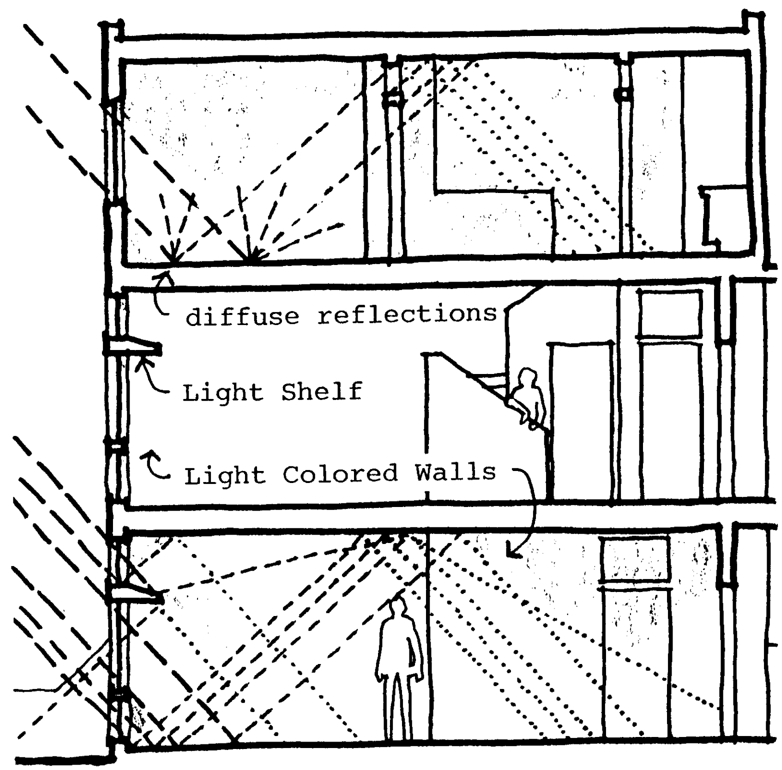
Natural daylighting is consistent with the energy conserving intent of solar architecture. Since the sun provides several times the amount of light required for most household activities, it should be capitalized upon. The weather's unpredictability makes artificial lighting unvoidable. However, on sunny days, the daylighting design should eliminate the need for any artificial sources.

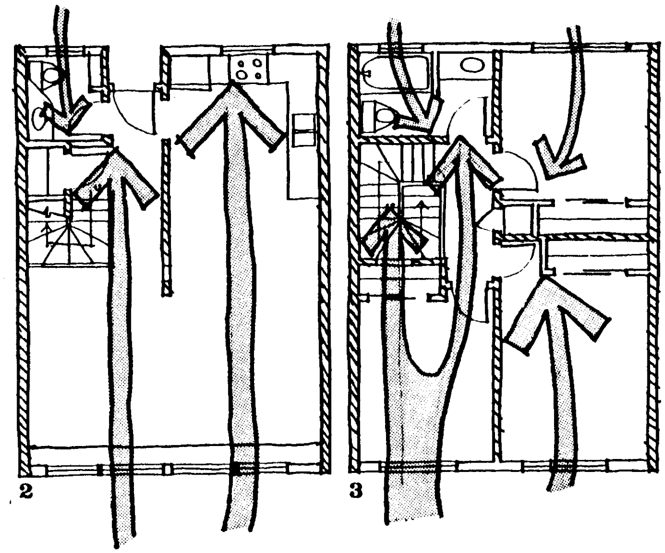
Daylight optimization also means maximizing the opportunities for sunlit spaces throughout the dwelling without jeopardizing it thermal integrity or comfort. Too many openings in the building skin produce excessive heat loss through infiltration or heat gain due to insolation. The resulting increased heating load or potential for overheating are both undesirable.

The plan organization works to fulfill the goal of daylighting optimization. All rooms are arranged to have at least one exterior exposure. The large south-facing living spaces, which are often occupied during the day, receive direct sunshine. Shallower rooms located on the north side make the best use of the diffuse light from the skyvault. Using light colors on the south facades of the adjacent buildings increases the amount of relected light entering those north rooms.

The overall room proportions in the units enhance the daylight penetration. High ceilings permit the use of tall windows. Usable daylight pentration in plan is twice the height of the windows.[8] Thus, the south-facing rooms of one-, two-, and four-bedroom units with their 9'-3" high south windows and maximum 18' depths, fall within the 1 to 2 ratio. These active zones also enjoy 15' to 18' of southern exposure. This yields an appropriate 1 to 1 depth to width ratio offering ample daylight pentration and uniformity. Living spaces in the three- and five-bedroom units are as deep as 28' and must therefore derive some of their light from north-

DAYLIGHT PENETRATION is enhanced by the combination of appropriate unit proportions, the light colored walls, the use of high windows and the light shelf.





PATHS OF LIGHT PENETRATION

SOLID WALLS are placed perpendicularly to the south window wall so as not to obstruct light.

facing windows.

The open plan design promotes daylight pentration by minimizing the number of partition walls and room divisions. Where solid walls are required, they are placed perpendicularly to the window wall so as not to obstruct light. Interior spaces that are removed from light borrowing which is achieved with transoms. Glazing is used above doors and closets to bring reflected light into stairways and hallways.

Light colored matte finishes where chosen for the walls and ceilings. Daylight striking these surfaces is reflected diffusely which improves the distribution of both light and heat energy.

Uniform illumination throughout a residential interior is not necessary because visual activities vary from one area of the house to another. However, the uneven light distribution resulting from single source lighting is a critical daylighting issue; rooms with one daylight source tend to be gloomy. Near the windows, sunlight is abundant but it discipates rapidly with the distance from the windows. Typical solutions to this problem such as roof monitors and skylights are inappropriate for multi-family housing because lower units have no roof exposure. Access to daylight in most rooms is limited to side lighting because of the party walls.

The reflectorized light shelf described in the solar heating section plays an important role in daylight distribution. It remedies much of the gloom encountered with single-source lighting. The incoming visible solar radiation from the south clerestory windows, redirected by the light shelf, make the white ceiling a large light source. With the light shelf placed just below the clerestory windows, its refletions are kept above the occupants eyes. A considerable amount of light is thrown deep into the space by the light shelf. This was made evident by the daylight testing reported in Appendicies 4e and 4f. Approximately 50 footcandles are redistributed deeper in the space.

Ground reflectance contributes a portion of the lighting in these low rise units. The underside of the light shelf intercepts some of this ground-reflected light to reduce the potential contrast glare or shadows created by the light shelf.

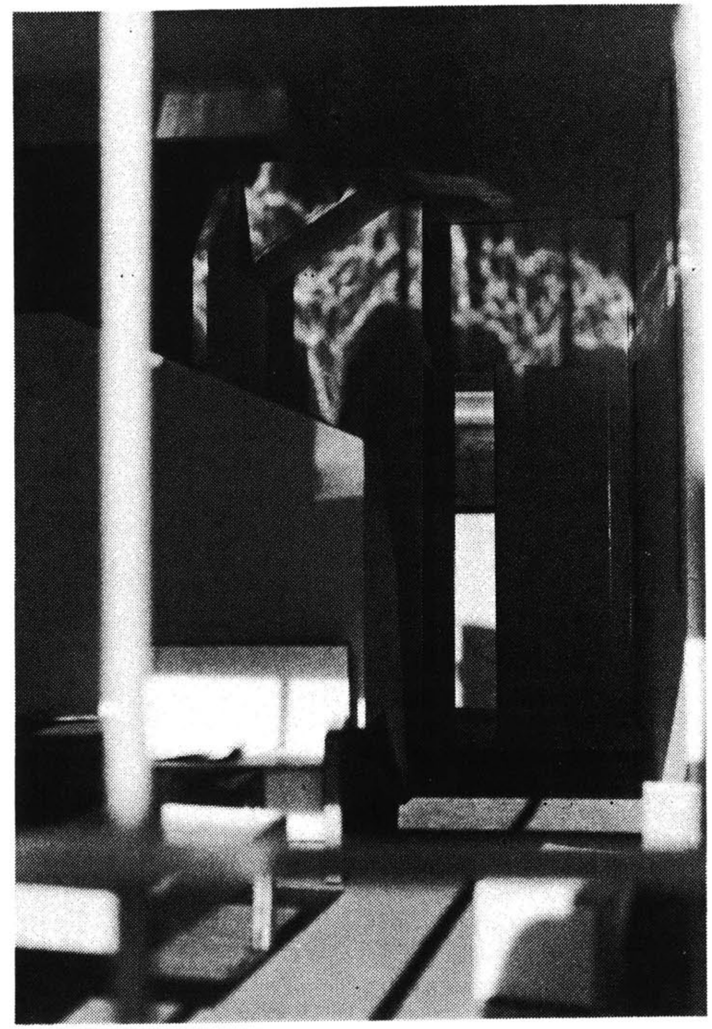


PHOTO OF THE DAYLIGHTING MODEL shows the light directing capabilities of the light shelf.

Glare Control

The tremendous amounts of south-facing glazing serving as solar collectors admit great quantities of light. Without thoughtout design, this light can create an uncomfortable luminous environment and negate the benefits of the solar heating design.

Glare can make a direct gain solar-heated dwelling visually uncomfortable. If the south-facing windows must be blocked to relieve the glare, the solar collecting purpose of the window windows is defeated.

Contrast glare, the visual effect produced by large luminous glass areas juxtaposed against darker interior surfaces, is minimized by extending windows to the corners of rooms. This allows the south facing windows to illuminate the walls perpendicular to them. Multi-directional lighting is also used wherever possible to help this situation. Deep reveals provide an even transition between the windows and the inside walls.

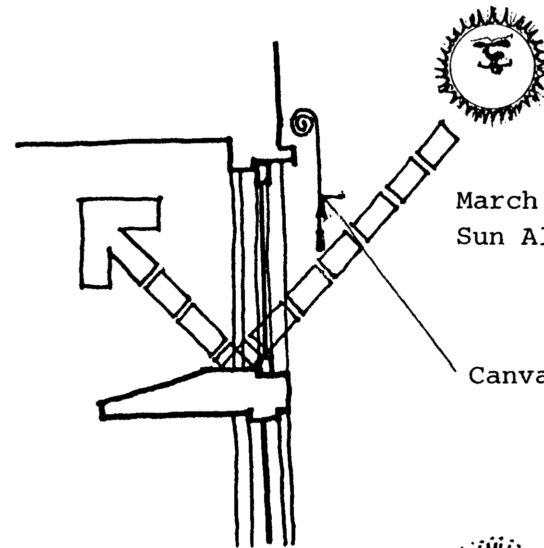
Bright sparkling glare is avoided by the use of non-reflective materials for the window assembly. Medium-colored carpeting and furnishings adjacent to the windows mitigate the glare potentially created by bright sun shining on the floor.

Shading

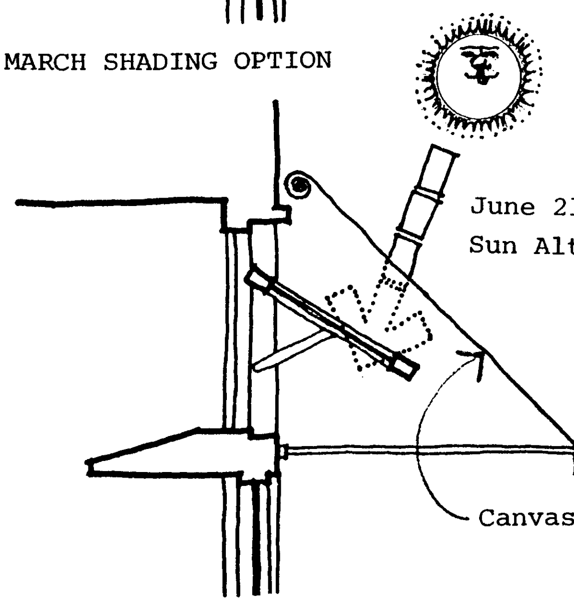
The adjustable shading device for the south facing windows allows the greates flexibility and control of the passive system and daylighting. The canvas awning can be carefully regulated by the occupants to the seasonal or even daily sun conditions. The amount of direct sunlight in the summer is reduced an average of 250 footcandles. Yet, an acceptable daylight factor of .28 is maintained. Enough light is admitted to render the unit bright and pleasant.

NATURAL VENTILATION

Though natural ventilation is taken for granted in homes, it is not as simple as just opening the windows. Natural ventilation deserves close attention in the design of this naturally tempered environment. Like passive solar heating and natural daylighting, the use of natural ventilation is rewarded by energy and ultimately, dollar savings. Furthermore, proper cross-ventilation is



MARCH SHADING OPTION



SUMMER SHADING
The canvas awning can be outstretched to allow the clerestory windows to be opened. No dircet sunlight strikes the light shelf.

critical; it is the sole source of summer cooling because air-conditioning is too expensive.

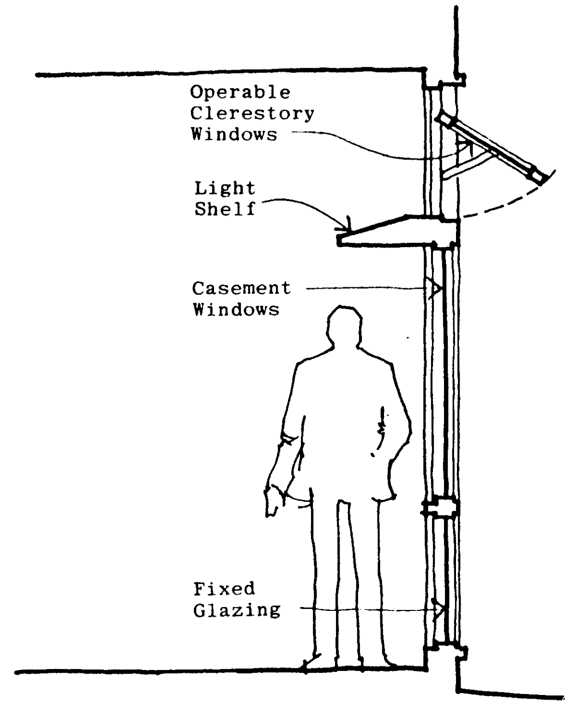
Natural ventilation completes the scheme of passive environmental tempering. The combination of these three techniques brings the urban dweller a heightened awareness and control of nature's forces. Once people become attuned to their environment they can derive innumerable benefits from its manipulation.

The main objective of natural ventilation design is to capitolize on the air movement produced by wind forces. A positive or high pressure zone is created on the windward face of a building. On the leeward side, a wind shadow, or negative low pressure zone is produced. Once access to the prevailing winds is assured, openings in the building enevelope are located to utilize these pressure differences. Placing an inlet in the windward wall and an outlet in the opposite, leeward site is the most effective method for inducing air movement.

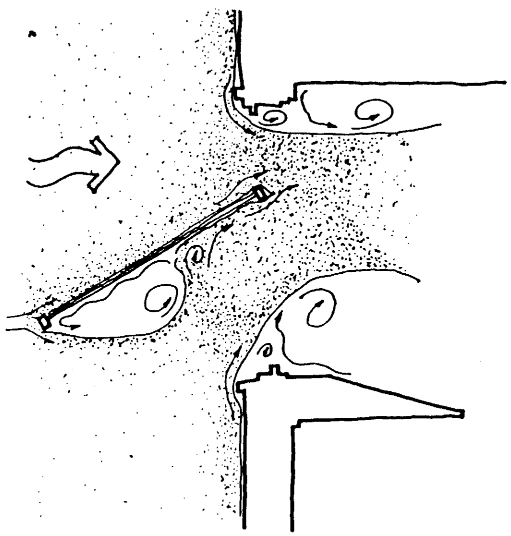
The number, size, type and location of air inlets and outlets determine the rate, quantity and pattern of air flow. Projected sash windows are used in the clerestory above the light shelf. and in the glazed band below desk height. The remaining operable windows in the unit are casement windows. These two types can be opened to their full dimension to allow the maximum air flow. By using different sized casement and projected sash windows, the amount of air admitted can be varied.

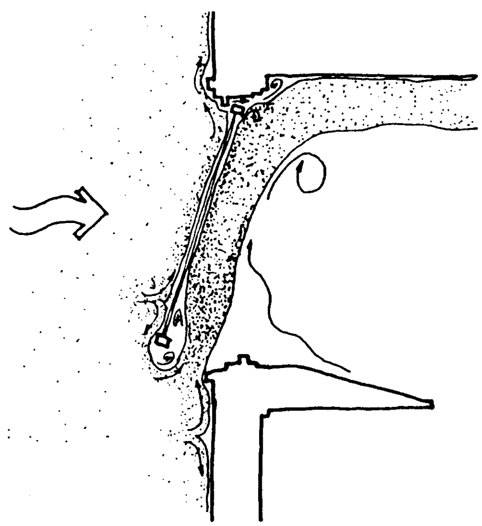
During the summer Boston experiences numerous hot, humid days. Evaporative cooling is quite effective for maintaining comfort in such weather. This process requires sufficient air speed which can be accomplished by combining a small inlet with a large outlet. The small opening on the windward wall results in a relatively high pressure which forces air through the inlet. The "Venturi effect" as it is called produces the necessary accelerated air movement through the unit.

The site organization and sloping topography allow the units to take full advantage of the prevailing southwest summer winds. Short rows of buildings and ample space between them permit the breezes to flow freely through the site. The slight southwesterly orientation



AIR FLOW PATTERN FOR SUMMER COOLING





SECTION OF PROJECTED SASH WINDOW shows how air can be deflected to the cieling for winter ventilation.

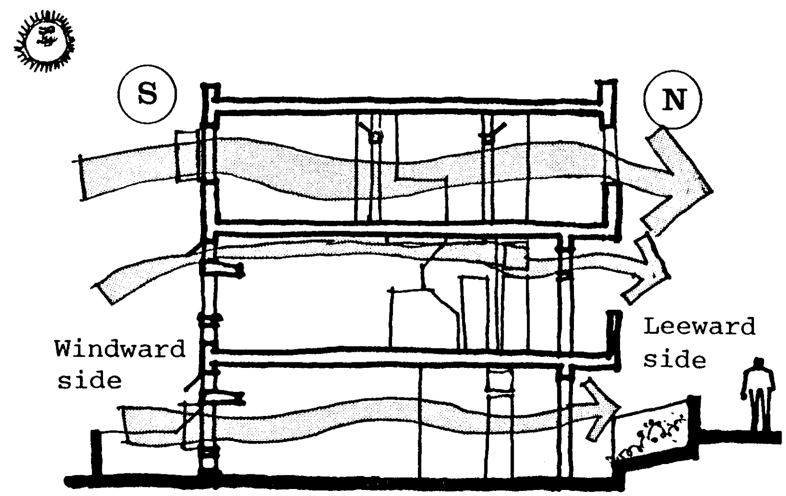
here proves to be an asset because it places the south wall of each building more squarely in line with the wind direction. The positive and negative pressure zones are thus established. Inlet and outlet openings occur in the south and north facades respectively to utilize these pressure differences.

A range of ventilation needs are served by the windows types chosen. Three or four large casement windows in the center band bring the welcomed summer breezes directly into the living zone. Each window provides ten square feet of opening. The clerestory windows can supplement the casement windows by removing hot air from the top of the room. These windows may also be used instead of the casement windows when indirect ventilation is preferred.

Venting a solar-heated building in winter is wasteful and should never be required to maintain a comfortable indoor temperature. However, if some air flow is desired, the clerestory windows are again useful. The projected sash windows can be adjusted to deflect incoming air to the ceiling where it mixes with the warmest room air in the upper portion of the room.

The flow-through design of the units emmulates this advantageous feature of triple deckers. Cross-ventilation as described above is fascilitated by the unit organization. Each floor may be ventilated independently. Additionally, the placement of the lavatories and some kitchens on the north wall of the units allows them to be vented directly to the exterior.

Abrupt changes in air flow direction caused by obstacles or partitions slow the air flow speed drastically. Here, however, the open plan permits the unobstructed flow of air as well as light and heat distribution. With the solid walls being perpendicular to the window wall and therefore parallel to the general air flow direction, they do not hamper ventilation. Where walls are needed for functional separation, transoms and doors may be opened to achieve cross-ventilation. Because rooms are gathered around small circulation spaces, air must travel only a short distance between rooms with few directional changes.



CROSS-VENTILATION is accomodated by the open plan and flow-through design.

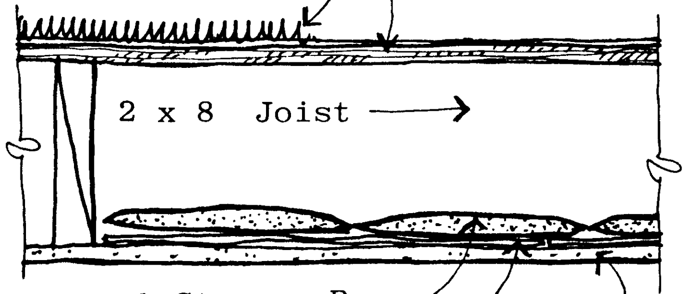
CHAPTER 5

AUXILIARY HEATING

Although the sun is harnessed to do the majority of the heating for these units, economic and solar access constraints make 100% solar heating difficult. Back-up heating systems are therefore required.

As shown in Appendix 3, the amount of available solar radiation is lowest during the winter months when the heating demand is the greatest. On a daily basis, a similar paradox occurs; solar heat gain is restricted to the daytime while the heat is needed at night. Successive cloudy days can deplete the heat stored in the building mass making supplimental heating necessary. This discrepancy between the heat from the sun and the total load is compensated for by the auxiliary heating system. Additionally, passive solar heating systems are unable to respond quickly to immediate demands for heat. The slow response time of passive systems reinforces the auxiliary heating need.

Like the passive solar system, the back-up system should be energy saving and economical to operate. Three auxiliary systems were initially investigated to find one most



INSTALLATION OF RADIANT HEATING MATS WITH PHASE CHANGE STORAGE MEDIUM

compatible with the solar design concepts already chosen. Electric radiant heating mats with phase change storage bags, water-to-air heat pumps and gas-fired warm air furnaces were the candidates. A fourth option for using the electric radiant heating mats alone, presented itself during the cost estimating phase.

The autonomy offered by the use of solar energy is carried through to the auxiliary heating system. Each of the options considered serves a single dwelling. The independence of the heating systems give the occupants flexibility and control. Energy conservation is also promoted in two ways. First, no energy is lost in heat distribution or transportation from a remote mechanical room. As with the passive solar, each option provides a heating system within the heated floor area. Second, residents can control their auxiliary heating use and can therefore conserve energy.

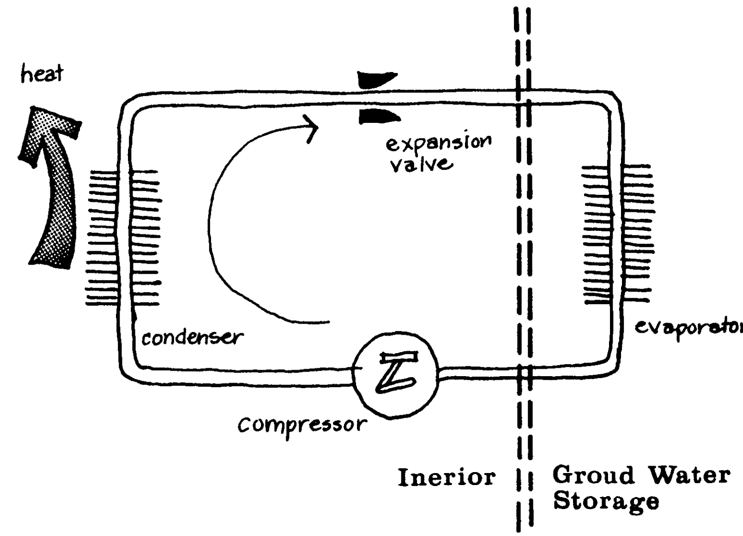
THE ALTERNATIVE SYSTEMS

The electric radiant heating mats work in conjunction with the phase change storage bags as described in Chapter 4. When the solar intake is low, off-peak electricity is used to charge the bags. The stored heat is relinquished when the room temperature drops sufficiently.

Electric radiant heating mats may also be used without the storage bags. With this application, off-peak heating cannot be done.

A water-to-air heat pump is a packaged unit which operates like a reversed refrigeration cycle. Heat is efficiently extracted from 50°F water. For the housing designed in this thesis, warm ground water is supposed to supply the 50°F water required. Freon, the circulation fluid, runs in a closed loop cycle. When the freon in a gaseous state passes through the warm water, heat is transferred to the cold freon. Next, electricity drives a compressor which increases the pressure and temperature of the freon. The freon then flows through coils where it condenses and gives off heat to the interior spaces.

The use of ground water in this climate presents a technical problem for the water-to-air heat pumps. During the winter the ground water temperature can drop well below



SCHEMATIC HEAT PUMP CYCLE

50°F especially because of the high water table on Mission Hill. Thus the system would be rendered ineffectual during the peak heating period.

The gas furnace is the most conventional of the four systems. Here, however, natural convection is employed for heat distribution.

System Comparisons

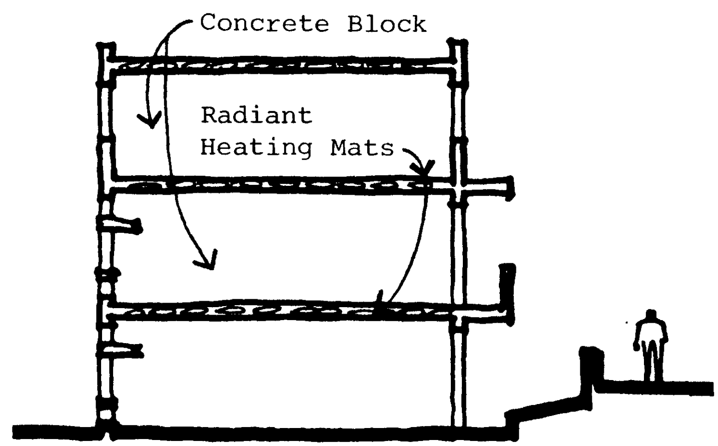
With respect to energy conservation and inexpensive operation, the heat pump is the most attractive system. For every kilowatt-hour of electrical energy put into a heat pump, three to four times the energy is output as heat.[9] The major drawback for heat pumps is cost. Units are $1,500 to $1,750 a piece, installed. Each zone to be heated -- typically a single room -- requires a unit. Providing just two heat pumps per home would exceed the price of a conventional heating system by at least 50%. A conventional system costs an average of $2,000. This figure is based on the cost of the heating and ventilation system used in the recently completed Viviendas II housing project by John Sharratt.

The heating mat and storage bag system

is not compatible with the passive solar system. However, if the light directing louvers can be replaced by the light shelf, the system is about the same price as a conventional system.

The modified gas-fired warm air system was selected for this design. Of the systems, explored, the balance between initial cost and operating cost is best met by this option. The initial cost of this system is $1500 and it costs $40.50 per year to operate.

At this point, the fourth auxiliary heating system must be mentioned. An electric radiant heating system using the mats alone has an initial cost which is lower than the gas-fired furnace system. Eliminating the thermal storage bags saves $936.90 making the entire cost $1,015.26. The yearly operating cost is $59.60. The choice gas-fired system is based on the current low price of natural gas which keeps the operating cost low. The radiant heating would only be viable if natural gas, once deregulated, followed the price trends of other fossil fuels and and cost of electricty could be lowered through the widespread use of coal



AUXILIARY HEATING SYSTEM using radiant heating mats alone and the concrete block party walls for storage.

for electricity production.

Appendix 5 outlines the initial and operating cost comparisons discussed above and also compares them to an oil-burning system.

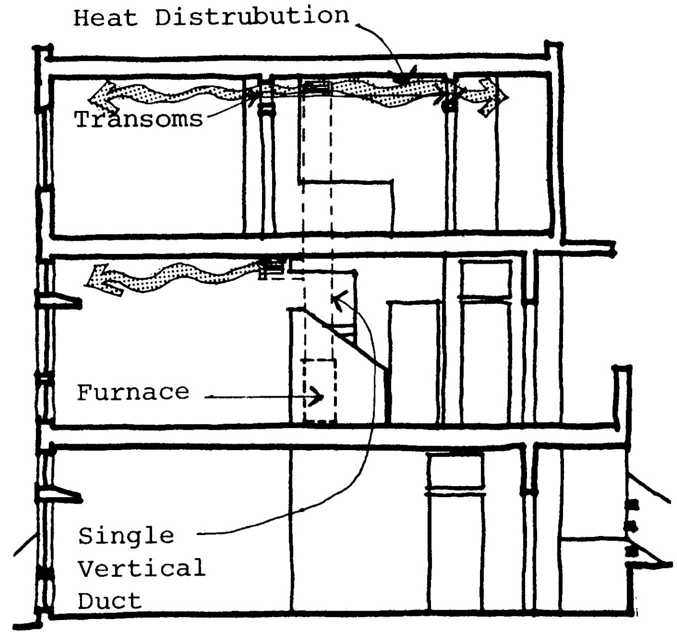
THE GAS-FIRED WARM AIR AUXILIARY HEATING SYSTEM

The rating, or heat generating capacity, for a back-up heating system is determined by the peak hourly load. The gas-fired furnace output is 40,000 BTUH which is more than enough to meet the January peak load of 15,125 BTUH. The additional heat capacity ensures the successful use of natural convection for warm air distribution.

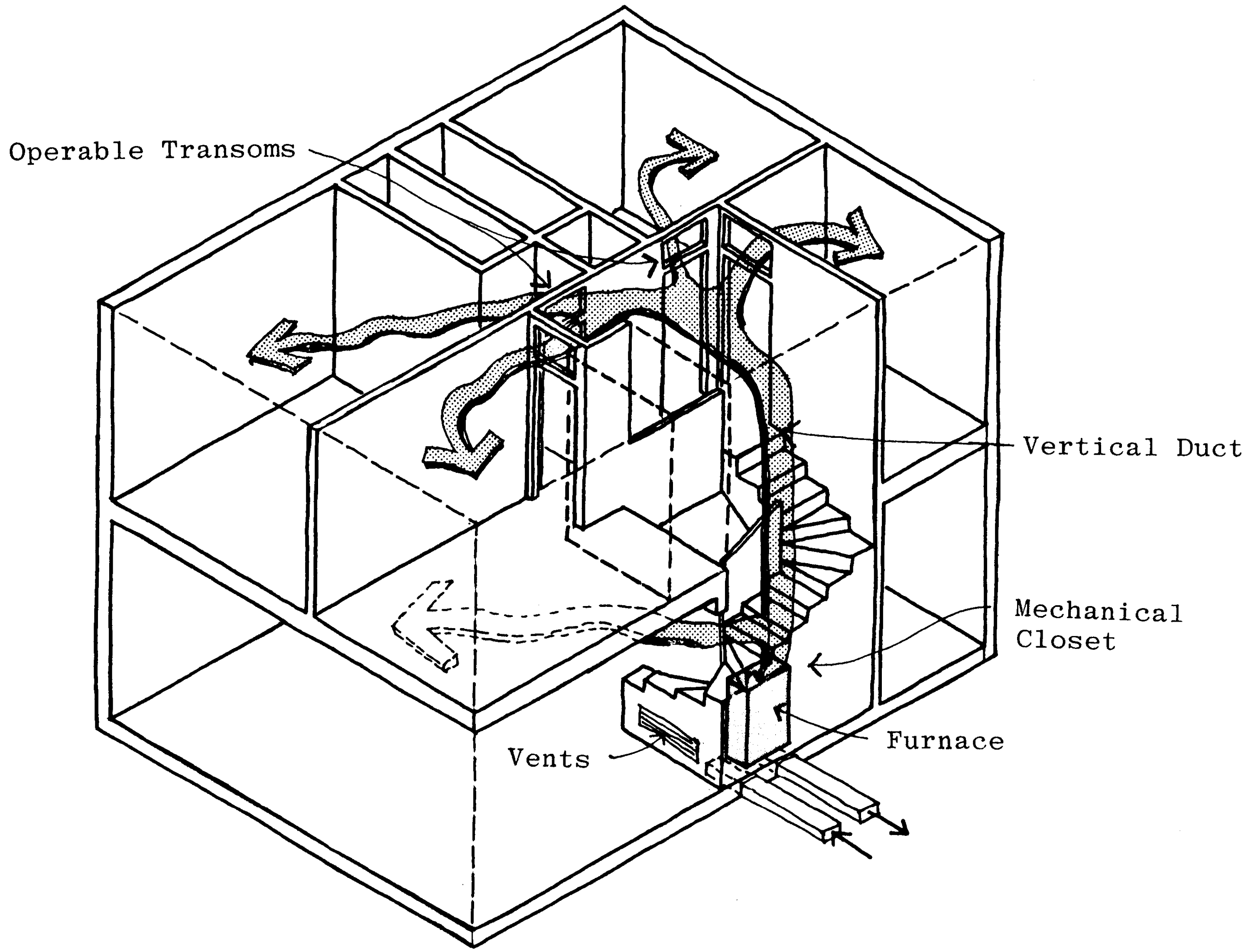
The warm-air furnaces are centrally located in each unit, and on the lowest level of the two-story units, to maximize the distribution of heat without branch ductwork. With this centralized location, the dwelling also benefits from the furnace's combustion heat. These compact furnaces are small enough (12" x 28 1/2" x 46") to be installed in a mechancial closet or under a stair. Combustion air is supplied by an air intake which can be shared by two dwellings. By code each furnace must have its own flue which is housed in a brick chimney in the concrete block party wall.

Ductwork from the furnace is limited to a single vertical shaft that vents at the ceiling on each level of the unit. This is where the additional capacity of the system is utilized. The air supplied by the modified system is at a much higher temperature than that from a furnace in a typical home (about 100°F). Hot air flows along the ceiling carried by the same convective currents that disperse collected solar heat. This layer of distinctly stratified hot air heats the ceiling making it a radiant heat source. Heat is then evenly distrubuted from the ceiling.

The gradual stratification problem that commonly occurs with typical warm air systems is eliminated because there is very little of the warm air mixing found in forced-air systems. The hot air mass remains at the top of the room. Also, the high ceiling height of 9'-0" to 9'-6" ensures that the living spaces below only receive the radiated heat. In two- and three-story units, a lip around the stairwell openings keeps the hot air mass from rising up the stair



HOT AIR is ducted vertically and then distributed by natural convection.

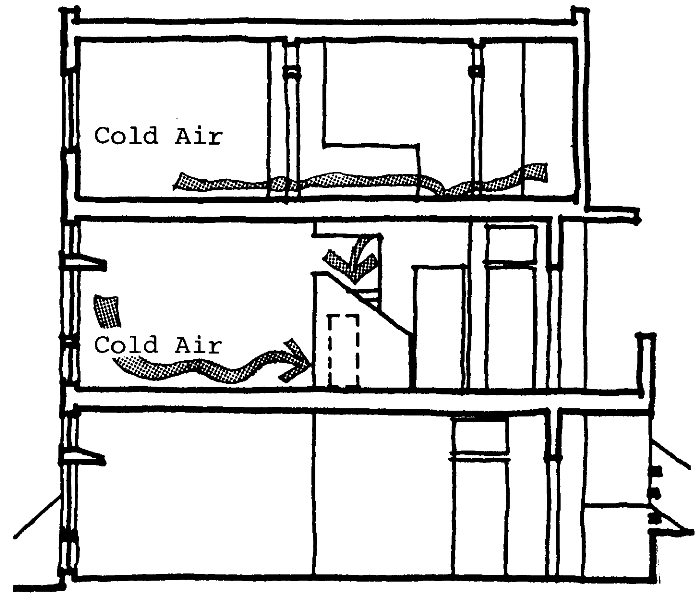


The Auxiliary Heating System

shaft which would circumvent the natural convection distribution.

Heat flow between rooms is accomodated by the open space planning and operable transoms above the doors. Air return is achieved by undercutting the doors. Cold air return in multiple story units occurs in the stairwell. Vents are used to facilitate the return air flow to the mechanical closet enclosure.

The use of natural convection eliminates the lengthy branch ductwork associated with forced air heating. The money saved from the reduction of ductwork goes into the solar budget.



COLD AIR RETURN
is facilitated by undercut
doors and the stairwell.

CHAPTER 6

DESIGN ANALYSIS

DESCRIPTION OF THE STANDARD UNIT

The cost and performance calculations and the daylighting studies presented in this thesis are based on the three-bedroom, two-story interior unit design. Because it is the predominant unit type on the site, it is an appropriate choice for estimating the qualitative and quantitative aspects of the natural environmental tempering scheme.

Throughout the design analysis a "standard unit" has been used for comparison purposes. This standard unit is analogous to the control case in a scientific study. It is the same three-bedroom unit described above except that it is designed to HUD Minimum Property Standards with no energy conscious considerations. A physical description and heat loss calculations for the standard unit can be found in Appendix 3. In Appendix 6, the cost balancing and solar budget are figured with respect to the construction of this standard unit.

SOLAR HEATING PERFORMANCE

The direct gain calculations using the Phillip Niles direct gain performance prediction model, analyse the interior temperature behavior on a clear March day. This method indicates the potential winter-time over-heating problems due to insufficient mass or excessive glazing.

Appendix 3b shows the direct gain spaces in the three- bedroom units do not suffer from overheating. The interior equilibrium temperature is about 63°F throughout the dwelling with an average temperature swing of ±8.25°F.

The maximum air temperature is 71.7°F and the minimum is 54.25°F. The 71.7°F maximum is quite comfortable; auxiliary heating might be needed to raise the air temperature if it were to drop below 63°F or so.

The net solar heating fraction is the per-cent of the dwelling's net solar heating load provided by the sun. The annual net solar heating fraction for the passive solar unit is 63% (62.8%). The results reported in Appendix 3d show that in April, May and November the solar gains more than offset the monthly loads. The solar heating fraction assumed for these months is 1.0 since the spaces do not overheat. The solar heating fractions of 1.0 mean that April, May and November, like the summer months, are not in the heating season.

The monthly auxiliary energy use for the four-month heating season is outlined in Appendix 3e. The sum of the monthly usage represents the annual auxiliary heating requirements. The cost of heating this unit is \$40.50 per year which breaks down to \$10.13 per month during the heating season. The energy conscious, solar heated dwelling consumes only 19.6% of the energy needed to heat the standard MPS unit. The solar heated unit has a load of 5.49 BTU/DD-°F-ft^2 for an energy efficient multi-family low-rise dwelling.

Assuming that a gas-fired system provides the auxiliary heating for the standard unit, the heating cost would be \$207 per year. The yearly energy savings accrued by the passive solar heated unit amount to \$166.50 (see Appendix 3h).

THE SOLAR BUDGET

The solar budget in Appendix 6 itemizes the additional costs and cost savings associated with the passive system.

Looking solely at the initial costs, the passive solar design adds $1,227.10 to the cost of the unit. This initial cost translates into a 99¢/ft^2 incerase in the cost of construction. When the heating savings are considered, the initial cost of the system is recouped in the first seven years of operation. A seven year payback period, figured on a straight line basis, is quite reasonable.

In multi-family housing, the construction cost and the rents that can be charged determine the design features to be included. Developers of such housing strive to minimize their initial cost to maximize the returns. Thus, the willingness of the lending institution to finance extra features is the ultimate deciding factor for their inclusion. The passive solar heating system is the extra feature in this housing.

Because these developers prefer to realize their profits immediately, life-cycle costs are usually far less important to them than front-end costs. For the subsidized housing proposed in this thesis, there is great concern for the life-cycle cost of housing because the developer is also the owner. The Back of the Hill Community Development Association intends to maintain ownership of the housing once it is built. The small initial investment in the passive solar system is easily justified by the resultant operating cost savings over the project life-cycle.

CHAPTER 7
CONCLUSIONS

Conclusions

This thesis has demonstrated the use of passive solar heating and energy conscious design in subsidized urban housing. The research and design work have been devoted to two major areas of interest. First, the integration of user-generated criteria for responsive housing and the various elements of natural environmental tempering was explored in an urban multi-family context to yield the architectural design response. Second, the supporting research and analysis addressed the implementation of the passive environmental tempering system within the economic constraints of subsidized housing. The design solution presented represents a step in the evolution of urban solar architecture. It has been intentionally designed to work within the existing constraints of the building industry and economic structure. It is shown that subsidized urban housing can be economically incorporate passive environmental tempering systems. Using a cost trade-off method, these systems add little to the initial cost of the housing and they provide a quick payback in operating costs. Furthermore, over the life cycle of the dwelling, the system saves thousands of dollars. Additionally, low- and moderate-income people benefit from the energy savings produced by the use of passive solar heating through reduced rents. The use of solar energy also promotes their economic self-sufficiency by reducing the dependence on fossil fuels.

Though this design solution is site specific, a good deal of broadly applicable information can be drawn from the study. For example, the simple, low-cost techniques and technologies described in this thesis may be readily applied to other urban housing design.

Further research might be directed toward developing new urban housing forms or fully exploring the opportunities offered by the alternative technologies.

This thesis adds to the body of knowledge on the use of passive solar energy use in urban housing. Hopefully, the information contained herein will prove useful to all who wish to tap the abundant energy from the sun.

APPENDICES

APPENDIX 1

MICROCLIMATE STUDIES

Appendix 1a

MICROCLIMATE ANALYSIS- Change in Profile Angle During Collection Period

Orientation: 0° (due south) Latitude: 40°N						5° west of south				
	April 21	Sept. 21	Oct. 21	Nov. 21	Dec. 21	April 21	Sept. 21	Oct. 21	Nov. 21	Dec. 21
8am	73°	50°	30°	14°	10°	81°	68°	35°	16°	10°
12 noon	62.5°	50°	39°	30°	26.5°	62°	50°	39°	30°	27°
4 pm	73°	50°	30°	14°	9°	65°	45°	25°	12.5°	8°
max. daily change	9.5°	0°	9°	16°	15.5°	19°	23°	14°	17.5°	19°

Orientation: 10° west of south						15° west of south				
8am	20°	67°	40°	19°	12.5°	no sun	79°	50°	24°	15°
12 noon	30°	51°	40°	31°	26.°	63°	51°	40.5°	31°	26°
4 pm	12°	40°	23°	11°	7.5°	56°	36°	41°	10°	7°
max. daily change	18°	27°	22°	20°	20°	63°	43°	9.5°	21°	19°

Orientation: 16.25° west of south					
8am	no sun	81°	52°	25°	15°
12 noon	52°	40.5°	27°	33°	27°
4 pm	53°	35°	20°	10°	7°
max. daily change	53°	46°	32°	23°	21°

Appendix 1b

MICROCLIMATE ANALYSIS

A method has been devised to pinpoint the time the sun reaches the highest point in its daily path. Solar noon, as this peak point is called, can be calculated by the following equation,

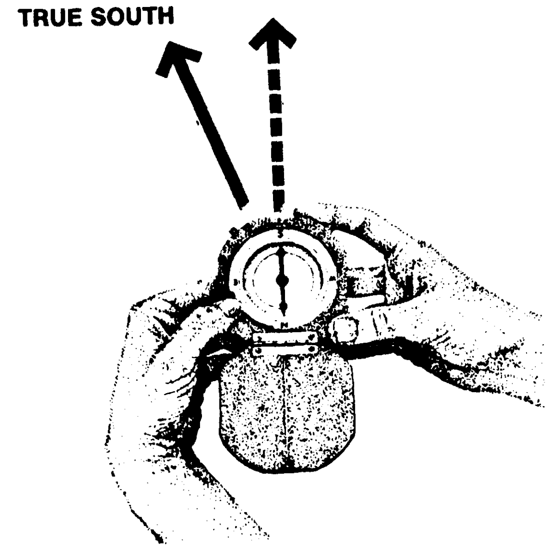
$$\text{Solar Noon} = \underset{\text{time}}{\text{Standard}} + \underset{\text{equation of time}}{\text{ET}} + 4\left(\underset{\text{Meridian}}{\text{Standard}} - \underset{\text{Meridian}}{\text{Local}}\right)$$

The equation of time correction for the earth's seasonal movement can be found on p. 253 of The Solar Home Book. The Eastern Standard Meridian is 75° and the Local Meridian is 71°. By setting the value of solar noon equal to 12:00 p.m., the equation can be solved for the local time that solar noon occurs.

Knowing this information, an experiment is set up on the site with a plumb bob on a stake, a compass and a watch. In a cleared area the stake is driven in the ground at an angle so that the plumb bob line casts a shadow. At the local time corresponding to solar noon, this shadow line strikes a north-south orientation which can

Appendix 1b

be checked against an adjusted magnetic compass reading. In this case the compass reading for the shadow line is 215.75° which must be adjusted 15° east to account for the local magnetic variation. Therefore, true south lies at 200.75° which is 16.25° east of the orthagonal street grid.



MAGNETIC COMPASS VARIATION
Source: Passive Solar Energy Book.

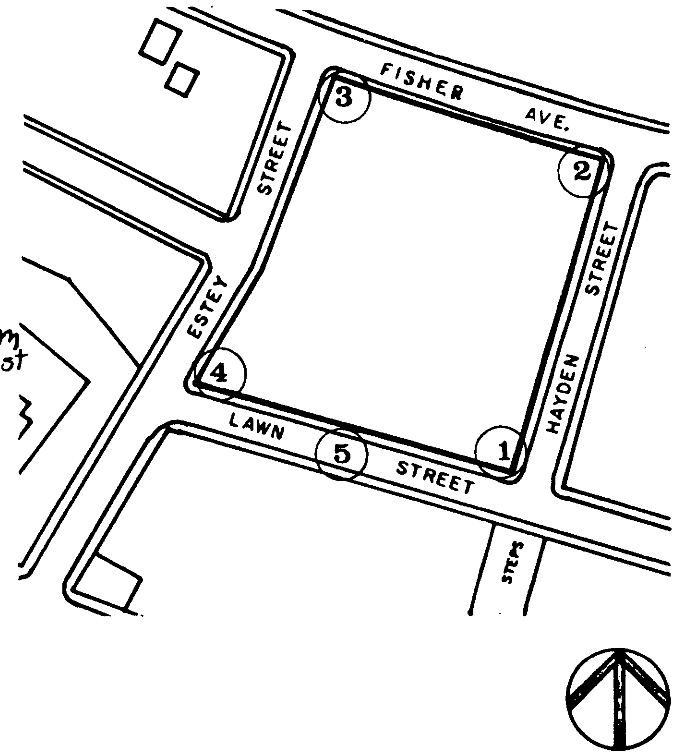
Appendix 1c

MICROCLIMATE ANALYSIS - Sun Path and Solar obstructions

Location: 1 Date	Conditions
June 21	no obstructions
Sept. 21	5:00 pm - on
Oct. 21	4:45 pm - on
Nov. 21	4:30 pm - on
Dec. 21	4:15 pm - on plus 7:45-8:15am shadow from homes to the east

Location : 2 Date	Conditions
June 21	no obstructions
Sept. 21	4:30 pm - 5:30 pm
Oct. 21	sunup - 9:30 am
Nov. 21	sunup - 10:00 am
Dec. 21	8:00 am - 10:00 am

Location : 3 Date	Conditions
June 21	unobstructed
Sept. 21	4:45pm - on shadow from decidous trees
Oct. 21	"
Nov. 21	4:30 pm - on
Dec. 21	4:00 pm - on shadow from deciduous trees



Appendix 1c (cont.)

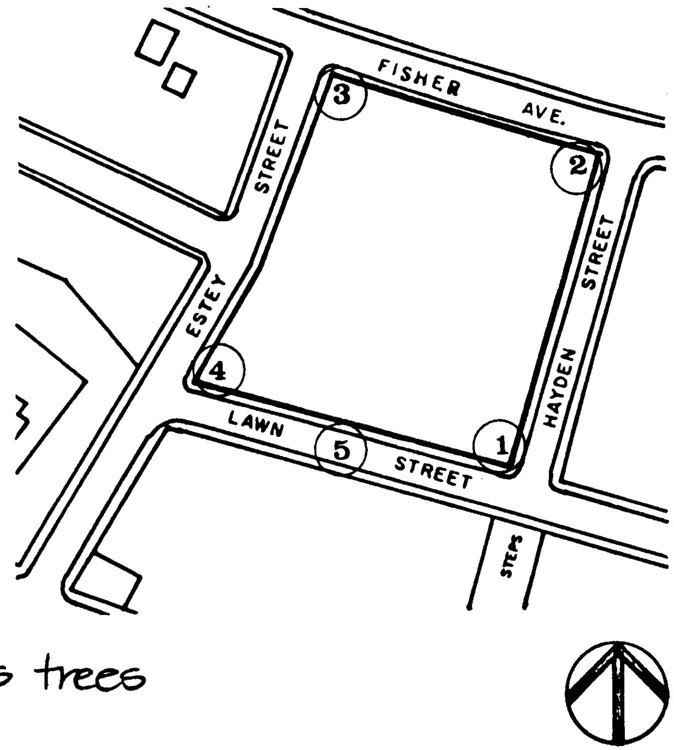
MICROCLIMATE ANALYSIS – Sun Path and Solar obstructions

Location: 4

Date	Conditions
June 21	unobstructed
Sept. 21	4:30pm – on shadow from hospital
Oct. 21	"
Nov. 21	3:45 pm – on
Dec. 21	3:30 plus shadow of decidous tree from 11:30 – 2:30

Location: 5

Date	Conditions
June 21	unobstructed
Sept. 21	"
Oct. 21	"
Nov. 21	"
Dec. 21	3:30 pm – on from decidous trees



Appendix 1d

MICROCLIMATE ANALYSIS - Night Air Flows Experiments

In understanding the microclimate of this site, the presence of cold air flows is important to identify. On a sloping site such as this there may be currents of cold air that flow downhill at night. Improperly sited building might dam this cold air creating cold air pockets which rob them of additional heat.

To check for night air flows, air and soil temperatures are taken at various points around the site. Smoke is used to determine the wind direction and flow. The experiments are conducted on clear nights following sunny days to ensure that the air movement is due to convection and that the land has recently received radiation. An 8°F temperature difference across the site would indicate the presence of the cold air flows.

RESULTS

The two tests performed show that cold air currents are not present on this site. Perhaps this is because the site is actually in the middle of a larger slope. Rapid cooling was noticed during the test period which is probably due to the site's exposure to the sky vault and wind from the southwest. The turbulant wind flow across the top of the site indicates that there is some protection provided by the hill to the north.

Appendix 1d

MICROCLIMATE ANALYSIS - Night Air Flows Data Sheets

MICROCLIMATE ANALYSIS

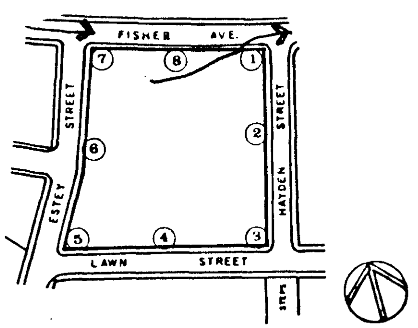
Night Air Flows Test 1

Date: Sept. 18, 1980
Time: 11:00 p.m.
Site Conditions: clear and chilly. Light wind

Testing time: 20 minutes

DATA:

loc.	°F
1	58.5
2	58.7
3	57.0
4	58.2
5	54.0
6	54.5
7	53.7
8	54.0



MICROCLIMATE ANALYSIS

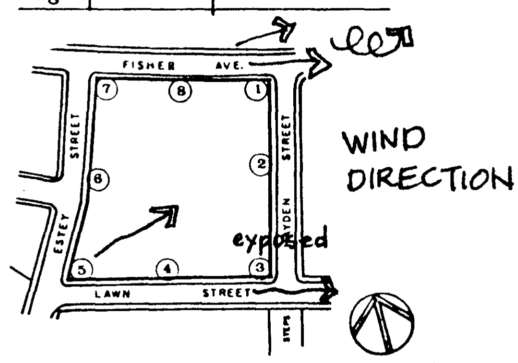
Night Air Flows Test 2

Date: Oct. 29, 1980
Time: 8:00 p.m.
Site Conditions: clear night following clear day

Testing time: 20 minutes

DATA:

loc.	°F Air	Ground °F
1	42	43
2		
3	40	41
4		
5	42	44
6		
7	44	45
8		



APPENDIX 2

HOUSING COST CALCULATIONS

HOUSING COSTS - Density Estimates

- The remainder of the Lahey land (10 acres) costs \$750,000.
- The site is a 1.33 acre portion of this land or 12.7%

  (.127) × (\$750,000) = \$94,994

- To bring the land cost contribution of the housing cost within HUD limits the number of units to be developed must be:

  @ an average cost of \$3,000/unit,

  $$\frac{\approx \$95{,}000}{\$3{,}000/\text{unit}} = \approx \underline{\underline{32 \text{ units}}}$$

  @ an average cost of \$2,000/unit,

  $$\frac{\approx \$95{,}000}{\$2000/\text{unit}} = \underline{\underline{47.5 \text{ units}}}$$

- With 47 units on the site the land cost is \$2021/unit.

  $\boxed{\text{47 UNITS ARE TO BE DEVELOPED}}$

- Density:

  $$\frac{47 \text{ units}}{1.33 \text{ acres}} = 35 \text{ dwelling units per acre,}$$

  which falls within the program goal of moderate density.

Appendix 2b

HOUSING COSTS- Housing Costs and Prices

- The average construction cost in Boston, projected for mid-1981 (from GBCD report) will be :

  $\$ 49.54 / ft^2$

- Housing Costs by Unit

Unit Type	Square feet	Construction Cost	Plus Development cost (15%)	HOUSING PRICE
1 BR	654□	$ 32, 399.16	$ 37, 259.03	$ 39, 280.03
1 BR (H)	678	33, 588.12	38, 626.30	40, 647.30
2 BR	956	47, 360.24	54, 464.27	56, 485.27
3 BR	1120	55, 484.80	63, 807.52	65, 828.52
3 BR (Flat)	1040	51, 521.60	59, 249.84	61, 267.84
4 BR	1344	66, 581.76	76, 568.68	78, 590.68
5 BR T.H.	1680	83, 227.20	95, 711.28	97, 732.

- Add 15% of the Construction Cost for the cost of Development

- Finally, the land costs are added to arrive at the final unit purchase price. (Land cost is $2021 /unit)

Appendix 2c

HOUSING COSTS- Rent Calculations

Rents are estimated by finding the debt service on the mortgage amount for each unit and then adding the additional monthly payments a homeowner must make.

ASSUMPTIONS

1. The debt service is calculated by the following equation:

$$\frac{\text{Principle} \times \text{Interest Rate}}{1 - (1 + \text{interest rate})^{-T}}.$$

2. The debt service is calculated based on a 20% downpayment.
3. The interest rate is 12%.
4. The mortgage term is 25 years.
5. The additional monthly payments include:

$ 50	Real Estate Tax
25	Insurance
25	Maintenance Reserve
80	Utilities
$ 180	/month added expenses

Unit Type	Housing Price	Minus 20% = Principle	Monthly Debt Service	Monthly Rent (+ $180)	HUD Fair Market Rents
1 BR	$ 39, 280	$ 31,424	$ 317	$ 497	$ 536
1 BR (H)	40, 647	32, 518	328	508	$ 536
2 BR	56, 485	45, 188	456	636	$ 629
3 BR	65, 828	52, 662	531	711	$ 742
3 BR (Flat)	61, 268	49, 014	495	675	$ 742
4 BR	78, 590	62, 874	635	815	$ 821
5 BR T.H.	97, 732	78, 186	790	970	

Appendix 2c

HOUSING COSTS – Analysis

Moderate-income residents are the target market of the homeownership program as discussed in Chapter 2. Moderate income is defined as "90% of the medium family income within the Boston SMSA." For a family of four the medium income is presently \$21,800 per year. By late 1981 this is projected to be \$23,000. So, 90% of this figure is:

$$\$21,800/\text{year} \times .9 = \$19,600.$$

Using the three-bedroom unit as an average-sized unit, the monthly payments made by the homeowner would be (previous page):

\$711 /month <u>OR</u> \$8,532 /year

Banks estimate that housing costs should represent, at most, 30% of a family's annual income. Thus, the annual income required to afford a three-bedroom unit is:

$$(x) \times .3 = \$8,532/\text{year}$$

$$x = \frac{\$8,532/\text{year}}{.3} = \boxed{\$28,440 \text{ Annual Income}}$$

The annual income calculated is \$8,884 more than the allowable income level for Section 235* elegibility.

* Section 235 is the HUD homeownership assistance program that would be used to finance such homeowership for moderate-income residents.

APPENDIX 3

SOLAR HEATING PERFORMANCE

Appendix 3a

The cost and performance calculations and the daylighting studies presented in this thesis are based on the three-bedroom, two-story interior unit design. Because it is the predominant unit type on the site, it is an appropriate choice for estimating the qualitative and quantitative aspects of the natural environmental tempering scheme.

Throughout the design analysis a "standard unit" has been used for comparison purposes. This standard unit is analogous to the control case in a scientific study. It is the same three-bedroom unit described above except that it is designed to HUD Minimum Property Standards with no energy conscious considerations. A physical description and heat loss calculations for the standard unit can be found below. The heat loss calculations for the two unit designs are done side by side-by-side for easy comparison.

Appendix 3a

MPS UNIT DESCRIPTION

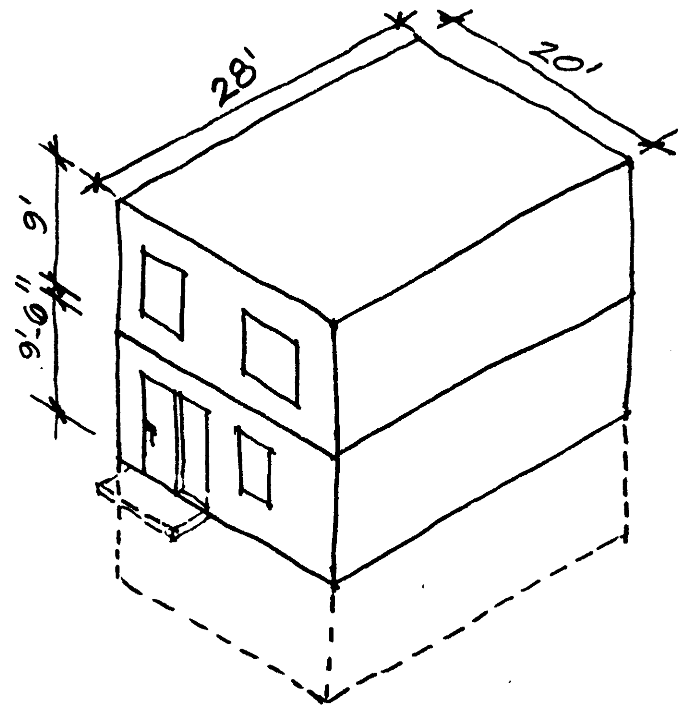
1. The standard unit is a three bedroom, two-story unit, 28' x 20' (length to width) occupying the second and third floors. It is an interior unit with a 560□' roof.

2. Rooms on the first level are 9'-6" hi high. Second level rooms are 9'-0".

3. Regular single glazing is used in the windows. (U-value 1.13). The sliding glass door in the Living room is doubled insulating glass (R-.69). The sliding glass door has 2 panels 6'-8" x 2'-6" each. Bedroom windows are 2'-6" x 4'-6" with one window per bedroom.

4. R-11 insulation is used in the walls.

5. Infiltration is taken to be 1 air change/hour.



Appendix 3a

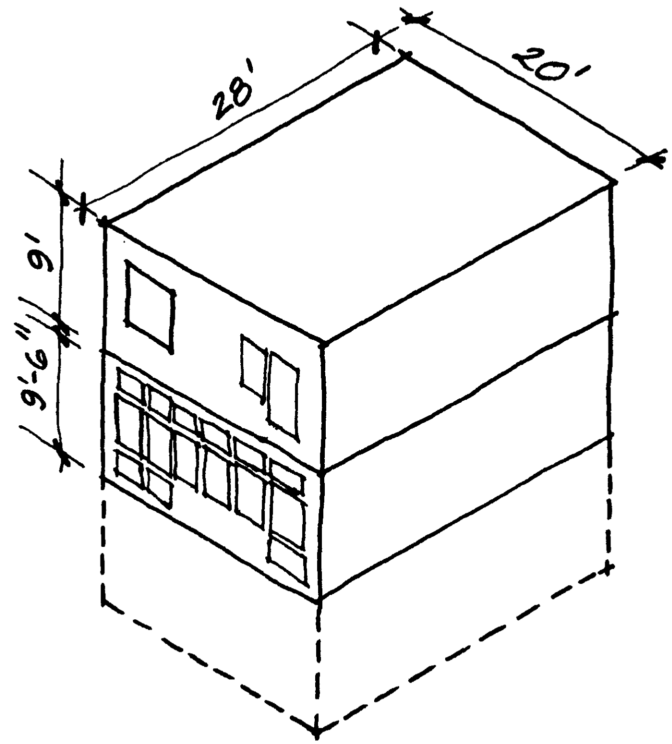
ENERGY CONSCIOUS UNIT DESCRIPTION

1. The Energy Conscious unit is the same design in the same location (i.e. interior duplex on the 2nd and 3rd levels). Room heights are the same.

2. Double glazing is used throughout the unit. U-values for the south windows is .55. North-facing windows use heat mirror in a double-glazed window assembly, U-value .29.

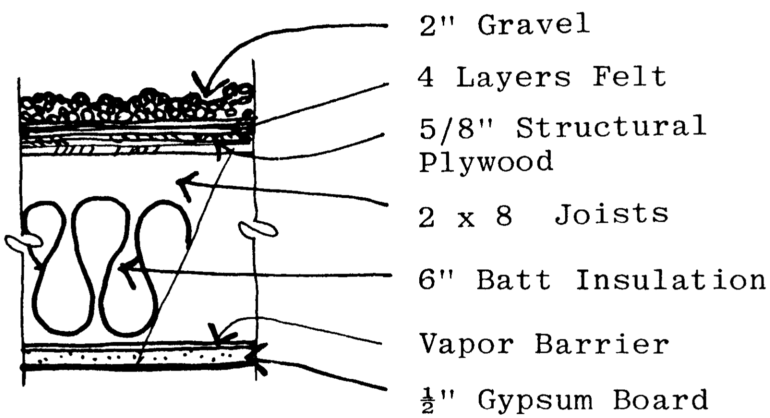
3. Tight construction brings the infiltration to .6 air change/hour.

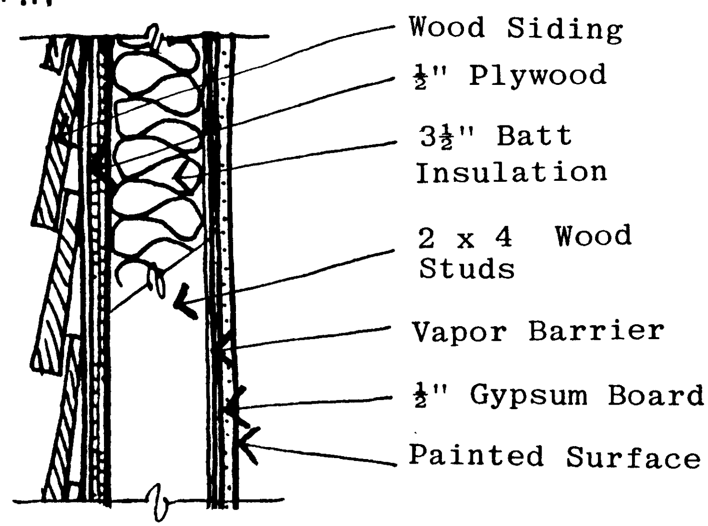
4. The wall insulation is 3½" Batt plus 1" Rigid Styrofoam.



Appendix 3a

UA Calculations for the Standard Unit

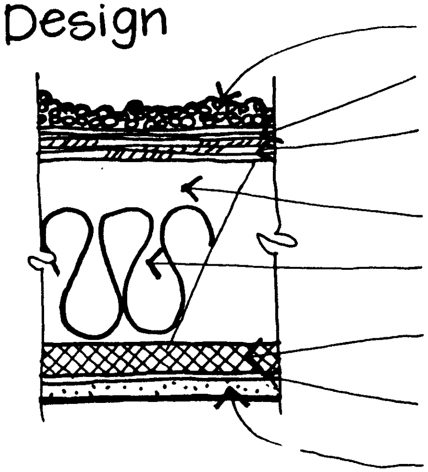


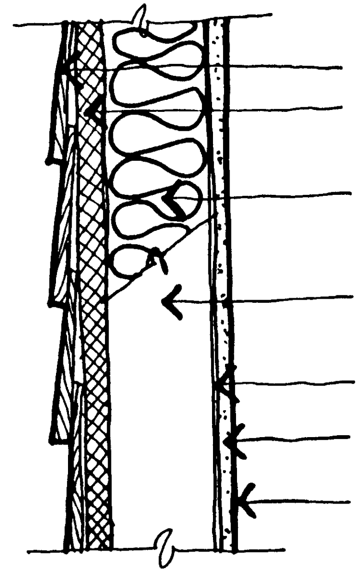


UA	Item	U-coeff.	Area (ft^2)	ΔT	Heat Loss (BTU/hr.)
57.0	Exterior wall	0.081	704.25	59	3365.6
23.3	Glass door	0.69	33.75	59	1374
84.75	Regular windows	1.13	75	59	5000.25
39.2	Roof	0.075	560	59	2312.8
					12,052.65
325.40	INFILTRATION LOSS (1 ac/hr)	.018	10,360 cu. ft.	59	19,199.15
529.69	BTU/hr/°F TOTALS				31,251.8 BTU/hr

Appendix 3a

UA Calculations for the Energy Conscious Design





UA	Item	U-coeff.	Area (ft^2)	ΔT	Heat Loss (BTU/hr)
28.2	Exterior wall	0.0583	484.05	59	1664.99
76.06	South glazing	0.55	138.3	59	4487.84
21.69	North glazing	0.29	74.8	59	1279.83
18.48	Roof (R-30)	0.034	560.0	59	1090.32
	INFILTRATION LOSS (.6 ac/hr)				
111.89		.018	10,360	59	6601.39

TOTALS

256.35 BTU/°F/hr

15,124.37 (BTU/hr)

Appendix 3a

MPS Standard Unit

- Seasonal Heating Load is: UA × 24 × Degree-Days

$529.96\ BTU/hr\text{-}°F \times 24\ hours/day \times DD$

The number of degree-days must be modified due to the heat provided by internal gains. Thus, a new Balance Point temperature is established.

$$\text{New } BP_{(°F)} = \text{Thermostat Setting} - \frac{\text{Internal Gains }(BTU/hr)}{UA_{total}\ BTU/hr/°F}$$

Internal Gains Estimate: Family of 4 produce about 70,000 daily

$70{,}000\ BTU/day \div 24\ hr/day = 2916.7\ BTU/hr$

$$\text{New Balance Point} = 65°F - \left(\frac{2916.7\ BTU/hr}{529.96\ BTU/hr/°F}\right)$$

$$= 65°F - (5.5°F) = \boxed{59.5°F}$$

For this balance point the number of Degree-days is $\boxed{3207.4}$

Seasonal Heating Load =

$(529.96\ BTU/hr\text{-}°F) \times (24\ hr/day) \times (3207.4\ DD) = 40{,}789{,}961\ BTU = \boxed{4.1 \times 10^7\ BTU}$

Appendix 3a

MPS Standard Unit Continued

Some solar Gain is experienced by the Standard Unit through its $67.5\ ft^2$ of South facing glass which lessens the Seasonal Heating Load.

Seasonal Solar Gain = $.655 \times 10^7$ BTU.

The Modified Seasonal Load = 4.1×10^7 BTU $-$ $.655 \times 10^7$ BTU = $\boxed{3.45 \times 10^7 \text{ BTU}}$

- Heating Costs

Assuming:
1. Gas-fired heater provides auxiliary heating
2. Gas is 60¢/therm (1 therm = 1×10^5 BTU).

The number of therms of gas needed to meet the Seasonal Heating Load is:

$$\frac{3.45 \times 10^7 \text{ BTU}}{1 \times 10^5 \text{ BTU/therm}} = 345 \text{ Therms}$$

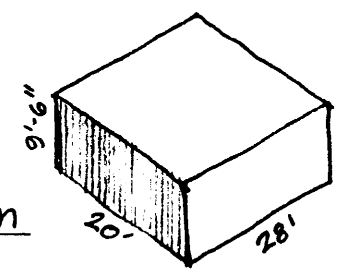
345 therms × 60¢/therm = $\boxed{\$ 207.00}$ or $\boxed{\$ 29.57/\text{month}}$ during the heating season

(Note: Calculations for the Energy Conscious Unit may be found in Appendix 3h)

Appendix 3b

OVERHEATING CALCULATIONS – March clear day Test

The following direct gain calculations use the Phillip Niles Direct Gain Performance Prediction Model to analyse the interior temperature behavior of the direct gain spaces on a clear March day. Again, the three-bedroom duplex unit is used. The Niles Method must be done by each direct gain zone. (The graphs referred to are in the Niles Model).



ZONE 1 : 1st floor of unit

1. Average Incoming Insolation (Q_s):

$$Q_s = \frac{\text{Solar Heat Gain} \times \text{Transmission Factor} \times \text{Pollution Correction}}{24 \text{ hrs/day}}$$

March, 40° N Latitude

$$Q_s = \frac{1388 \text{ BTU/ft}^2\text{/day} \times .72 \times .80}{24 \text{ hrs/day}} = \boxed{33.3 \text{ BTU/ft}^2\text{/hr}}$$

Transmission Factor for double glazing = (.85) x (.85) = .72
Pollution Correction due to Atmospheric Conditions = .80 or 80%

2. Estimating equilibrium temperature (T_e):

Area south-facing Glass (A_g) = 98 □'

The heat loss with and without the south-facing glass is calculated below for Zone 1. UA_{ns} is the heat loss without the south-facing glass contribution.

Appendix 3b

UAns calculations

UA	Item	U- coef.	Area	ΔT	Heat Loss (BTU/hr)
· 13.26	exterior wall	0.0583	$227.45 ft^2$	59	782.35
53.9	south glass	0.55	98.0	59	3180.10
· 3.42	north glass	0.29 (heat mirror)	11.8	59	201.89
	INFILTRATION	LOSS	.6 AC/HR		
· 57.46		.018	$3,192 ft^3$	59	3389.9

· 74.14 UAns | 7,554.24 BTU/hr

128.04 UA_{TOTAL}

$$Te = \frac{\text{Area south glass (Ag)} \times \text{Average Insolation}}{UA_{\text{TOTAL}}} + T_{out}\ (°F)$$

$$= \frac{98 ft^2 \times 33.3\ BTU/ft^2/hr}{128.04\ BTU/hr/°F} + 38.1\ °F$$

$$Te = 25.49\,°F + 38.1\,°F = \boxed{63.59\,°F}$$

3. Outdoor Temperature Amplitude :

$$A_{out} = \frac{T_{max.\ avg} - T_{min.\ avg}}{2} = \frac{15\,°F}{2} = \pm 7.5\,°F$$

4. Zero Mass Amplitude :

$$Te - T_{out} = 63.59\,°F - 38.1\,°F = 25.49\,°F$$

zero mass amplitude (from graph) – $\boxed{A_z = 47°F}$

5. Effective Mass Storage Capacity:
The effective participating mass for storage is the 2" of the concrete block wall before the cavity. Thus in each wall there is:

$$2'' = .166 \text{ ft}$$

$$(.166 \text{ ft}) \times (9.5' \text{ high walls}) \times (28') \times 2 = 88.31 \text{ cubic feet of storage}$$

Because a diffuse light distribution scheme is used, the full depth of the unit is considered as storage.
The effective Mass Capacity (MC_s) for 2" concrete = 4.99 BTU/ft²/°F

6. Thermal Conductivity (h):
For wall storage h = 1.

7. Temperature Swings—Convective Case:

$T_e = 63.59\,°F$

$T_{out} = 38.1\,°F$

$Q_s = 33.3 \text{ BTU/ft}^2\text{/hr}$

$$a = \left(\frac{\text{storage area}}{\text{area glass}}\right) = \left(\frac{532\,\square'}{98\,\square'}\right) = 5.42$$

$h = 1$

$A_{out} = \pm 7.5\,°F$

$$\bullet\ \frac{(T_e - T_{out})\,a \cdot h}{Q_s} = \frac{(63.59 - 38.1)(5.42)(1)}{33.3} = \boxed{5.18}$$

$$\bullet\ \frac{MC_s}{h} = \frac{4.99}{1} = 4.99$$

A_c/A_z (from graphs) = .24

Thus,

$A_c = A_z\left(\frac{A_c}{A_z}\right) = 47°F \times .24 = 11.28°F$

Max. air temp. = 63.59 (T_e) + 11.28 °F = $\boxed{74.87°F}$

Min. air temp. = 63.59 − 11.28 °F = $\boxed{52.31°F}$

8. Temperature Swings – Radiative Case:

(This is the case that will be found in the direct gain spaces because the mass is heated directly rather than the air.)

$$\frac{T_e - T_{out}}{A_{out}} = \frac{63.59°F - 38.1°F}{+7.5°F} = 3.4$$

graph yields: $A_r/A_c = .72$

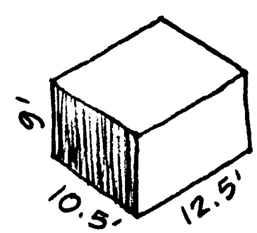
$A_r = A_c \times .72 = (11.28°F) \times .72 = 8.12°F$

ZONE 1

→ Max. air temp. = 63.59°F + 8.12 °F = $\boxed{71.71°F}$

→ Min. air temp. = 63.59 °F − 8.12 °F = $\boxed{55.47°F}$

<u>ZONE 2:</u> Large Bedroom



1. Average Incoming Insolation:

Q_s = 33.3 BTU/ft²/hr

Appendix 3b

2. Estimating equilibrium temperature (Te):

UA	Item	U-coef.	Area	ΔT	Heat Loss (BTU/hr)
· 4.23	exterior wall	0.0583	72.5	59	249.4
12.1	south glass	0.55	22	59	713.9
· 4.3	Roof	0.033	131.25	59	255.5
· 12.75	INFILTRATION	LOSS 0.018	1181.25 ft^3	59	752.69

· 21.28 UA_{ns}

33.4 UA_{TOTAL}

1971.49 BTU/hr

$$Te = \frac{22 ft^2 (\text{glass}) \times 33.3\ BTU/hr/ft^2\ (\text{avg. insolation})}{33.4\ BTU/hr/°F} + 38.1°F\ (T_{out})$$

$$Te = 21.9\,°F + 38.1°F = \boxed{60.03\,°F}$$

3. Outdoor Temp. Amplitude : ± 7.5°F

4. Zero Mass Amplitude:

$Te - T_{out} = 60.03\,°F - 38.1°F = 21.9°F$

Zero Mass Amplitude (from graphs) – $\boxed{A_z = 44.5°F}$

5. Effective Mass Capacity:

MC_s for 2" concrete = 4.99 $BTU/ft^2/°F$

6. Storage thermal Conductivity : h = 1

7. Temperature Swings - Convective Case:

$T_e = 60.03\ °F$

$T_{out} = 38.1\ °F$

$Q_s = 33.3\ BTU/ft^2/hr$

$a = \left(\dfrac{112.5\ ft^2\ \text{storage}}{22\ ft^2\ \text{glass}}\right) = 5.1$ {for concrete block wall alone

$h = 1$

$A_{out} = 7.5°F$

- $\dfrac{(T_e - T_{out})\,a \cdot h}{Q_s} = \dfrac{(60.03\ °F - 38.1°F)(5.1)(1)}{33.3} = \boxed{3.4}$

- $\dfrac{MC_s}{h} = \dfrac{4.99}{1} = 4.99$

A_c/A_z (from graph) $= .26$

Thus,

$A_c = A_z\left(\dfrac{A_c}{A_z}\right) = 44.5°F \times .26 = 11.57\ °F$

Max. air temp. $= 60.03\ °F + 11.57°F = \boxed{71.60\ °F}$

Min. air temp. $= 60.03\ °F - 11.57°F = \boxed{48.46\ °F}$

8. Temperature Swings - Radiative Case:

$\dfrac{T_e - T_{out}}{A_{out}} = \dfrac{60.03 - 38.1\ °F}{7.5\ °F} = \dfrac{21.93\ °F}{7.5\ °F} = 2.9$

Appendix 3b

graph yields: $Ar/Ac = .73$

$Ar = Ac \times .73 = (11.57\,°F) \times .73 = 8.45\,°F$

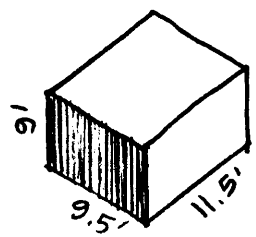
ZONE 2

→ Max. air temp. = 60.03 °F + 8.45 °F = $\boxed{68.48\,°F}$

→ Min. air temp. = 60.03 °F − 8.45 °F = $\boxed{51.58\,°F}$

ZONE 3: Small South Facing Bedroom

1. Average Incoming Insolation:
   $Qs = 33.3$ BTU/ft²/hr



2. Estimating equilibrium temperature (Te):

UA	Item	U-coef.	Area	ΔT	Heat Loss (BTU/hr)
• 3.92	exterior wall	0.0583	67.2	59	231.15
10.07	south glass	0.55	18.3	59	593.84
• 3.71	roof	0.033	109.25	59	219.15
• 10.62	INFILTRATION	LOSS .6 0.018	AC/HR 938.25ft³	59	626.53

• 18.25 UAns

28.34 UA TOTAL

1670.67 BTU/hr

Appendix 3b

$$T_e = \frac{18.3\,ft^2 \times 33.3\ BTU/ft^2/hr}{28.34\ BTU/hr/°F} + 38.1\,°F =$$

$$= 21.5\,°F + 38.1\,°F = \boxed{59.6\,°F}$$

3. Outdoor Temp Amplitude: $\pm 7.5°F$

4. Zero Mass Amplitude:
   $T_e - T_{out} = 59.6\,°F - 38.1\,°F = 21.5°F$
   Zero Mass Amplitude (from graph) $- \boxed{A_z = 44.0°F}$

5. Effective Mass Capacity:
   MC_s for 2" concrete $= 4.99\ BTU/ft^2/°F$

6. Storage Thermal Capacity: $h = 1$

7. Temperature Swings – Convective Case:
   $T_e = 59.6\,°F$
   $T_{out} = 38.1\,°F$
   $Q_s = 33.3\ BTU/ft^2/hr$
   $a = \left(\frac{103.5\,ft^2 \text{ storage}}{18.3\,ft^2 \text{ glass}}\right) = 5.66$
   $h = 1$

- $\frac{(T_e - T_{out})\,a \cdot h}{Q_s} = \frac{(59.6\,°F - 38.1\,°F)(5.66)(1)}{33.3} = \boxed{3.65}$
- $MC_s \div h = 4.99 \div 1 = 4.99$

Ac/Az (from graph) = .25

Thus,

$$Ac = Az\left(\frac{Ac}{Az}\right) = 44.0°F \times .25 = 11.0°F$$

Max. air temp. = 59.6 °F + 11.0 °F = $\boxed{70.6\ °F}$

Min. air temp. = 59.6 °F − 11.0 °F = $\boxed{48.6\ °F}$

8. Temperature Swings- Radiative Case:

$$\frac{Te - Tout}{Aout} = \frac{59.6\ °F - 38.1\ °F}{7.5°F} = \frac{21.5\ °F}{7.5°F} = 2.9$$

graph yields : $Ar/Ac = .735$

$Ar = Ac \times .735 = (11\ °F) \times .735 = 8.1\ °F$

ZONE 3

→ Max. air temp = 59.6 °F + 8.1 °F = $\boxed{67.7°F}$

→ Min. air temp = 59.6 °F − 8.1 °F = $\boxed{51.5°F}$

Appendix 3c

MODIFIED BUILDING LOAD - Energy Conscious Unit

Modified Building Load = (Degree-days/Month) × (UA) × (hours/day)

	Degree-Day	UA (BTU/hr/°F)	hours/day	LOAD (BTU)
Jan.	756.6	256.35	24	4,654,905.8
Feb.	649.8	256.35	24	4,059,353.5
Mar.	481.2	256.35	24	2,960,288.7
Apr.	159.8	256.35	24	983,399.6
May	22.3	256.35	24	137,075.5
June	.72	256.35	24	4,429.73
July	0	256.35	24	0
Aug.	0	256.35	24	0
Sept.	3.16	256.35	24	19,441.58
Oct.	54.88	256.35	24	337,643.71
Nov.	237.88	256.35	24	1,463,532.9
Dec.	638.6	256.35	24	3,928,922.5
TOTAL				18,191,907 BTU

Appendix 3d

SOLAR INTAKE — South Facing Glazing

Solar Intake = (Average Daily Horiz. Radiation) x (Factor A) x (Transmission Factor) x (Shading Factor) x (Tilt Factor) x (Days/Month) x (Glass Area)

	Jan.	Feb.	Mar.	Apr.	May	June
Average Horizontal Radiation	475 BTU/ft²/day	710	1016	1326	1620	1817
Factor A	1.303	1.050	0.731	0.476	0.336	0.288
Transmission Factor	.72	.72	.72	.72	.72	.72
Shading Factor	.95	.95	.95	.95	.95	.95
Tilt Factor	1	1	1	1	1	1
No. of Days in Month	31	28	31	30	31	30
South Glazing Area	138.3 ft²	138.3	138.3	138.3	138.3	138.3
TOTAL BTUs	1,815,005.7	1,974,621.8	2,177,965.7	1,791,224.2	1,596,225	1,485,070

Appendix 3d (cont.)

July	Aug.	Sept.	Oct.	Nov.	Dec.	TOTAL
1749	1486	1260	890	503	403	
0.305	0.397	0.60	0.901	1.203	1.366	
.72	.72	.72	.72	.72	.72	
.95	.95	.95	.95	.95	.95	
1	1	1	1	1	1	
31	31	30	31	30	31	
138.3	138.3	138.3	138.3	138.3	138.3	
1,564,334	1,730,013	2,145,464	2,351,553	1,717,248	1,614,343	19,611,513 BTU annually

Appendix 3e

SOLAR INTAKE - North Facing Glazing

Solar Intake = (Transmitted Reflected and Diffuse Radiation) x (Glass Area) x (Days/ Month)

	Transmitted	Glass Area	Days/Month	BTU/Month
Jan.	111.5 BTU/ft/day	74.8	31	258,546.2
Feb.	153.65	74.8	28	321,804.56
Mar.	208.6	74.8	31	483,701.68
Apr.	281.75	74.8	30	632,247.0
May	393.4	74.8	31	912,215.92
June	462.9	74.8	30	1,038,747.6
July	407.98	74.8	31	946,024.02
Aug.	300	74.8	31	695,640.0
Sept.	218.2	74.8	30	489,640.8
Oct.	161	74.8	31	373,326.8
Nov.	115.3	74.8	30	258,733.2
Dec.	95.1	74.8	31	220,517.88
				6,631,145.6 BTU/yr.

Appendix 3f

NET SOLAR HEATING FRACTION for Energy Conscious Unit

$$\text{SHF} = \frac{\text{Solar Intake}}{\text{Modified Building Load}}$$

	Jan.	Feb.	Mar.	Apr.	Nov.	Dec.
Solar Intake South (BTU)	1.82×10^6	1.97×10^6	2.18×10^6	1.79×10^6	1.72×10^6	1.61×10^6
Solar Intake North (BTU)	$.26 \times 10^6$	$.32 \times 10^6$	$.48 \times 10^6$	$.63 \times 10^6$	$.26 \times 10^6$	$.22 \times 10^6$
Monthly Modified Load (10^6 BTU)	4.65×10^6	4.06×10^6	2.96×10^6	1.27×10^6	1.46×10^6	3.93×10^6
SHF %	.447 44.7%	.564 56.4%	.898 89.8%	1.0 100.0%	1.0 100.0%	.466 46.6%

MONTHLY AUXILIARY ENERGY USE

Monthly Auxiliary Energy Use = (Modified Building Load) − (Solar Intake)

	Jan.	Feb.	Mar.	Dec.	TOTAL
Monthly Building Load (10^6 BTU)	4.65	4.06	2.96	3.93	15.6×10^6 (BTU)
Solar Intake (10^6 BTU)	2.08	2.29	2.66	1.82	8.85×10^6
Monthly Auxiliary Energy Use (BTU)	2.57	1.77	.30	2.11	6.75×10^6 Annually (BTU/year)

Appendix 3h

HEATING COSTS AND SAVINGS - Energy Conscious Unit

Appendicies 3c through 3g present the calculations for the solar gain in the unit and its effect on the Seasonal Heating Load. From Appendix 3g:

Modified Seasonal Load = 1.56×10^7 BTU $-$ $.885 \times 10^7$ BTU (solar gain) = $\boxed{.675 \times 10^7 \text{ BTU}}$

- This is the annual energy use for the solar/energy conscious unit. Again assuming:
  1. a gas-fired heater provides the heating
  2. Gas is 60¢/therm,

The annual energy use is:

$$\frac{.675 \times 10^7 \text{ BTU}}{1 \times 10^5 \text{ BTU/therm}} = 67.5 \text{ therms}$$

67.5 therms × 60¢/therm = $\boxed{\$40.50}$ OR $\boxed{\$10.13/\text{month}}$ during the four-month heating season

- Energy Use Savings

A comparison can now be made between the Energy Conscious Unit Design and the Standard Unit. The Energy Conscious Unit with its integrated passive solar heating only consumes 20% (19.6%) of the

HEATING COSTS AND SAVINGS - Continued

energy required to heat an identical apartment of average MPS construction.

The use of solar energy and energy conservation produces a yearly dollar savings that suppliments the Solar Budget.

$207.00	Typical MPS standard Unit (w/ gas heat)
40.50	Energy Conscious Unit (w/ gas heat)
$\boxed{\$166.50}$	Annual savings on Energy Bill

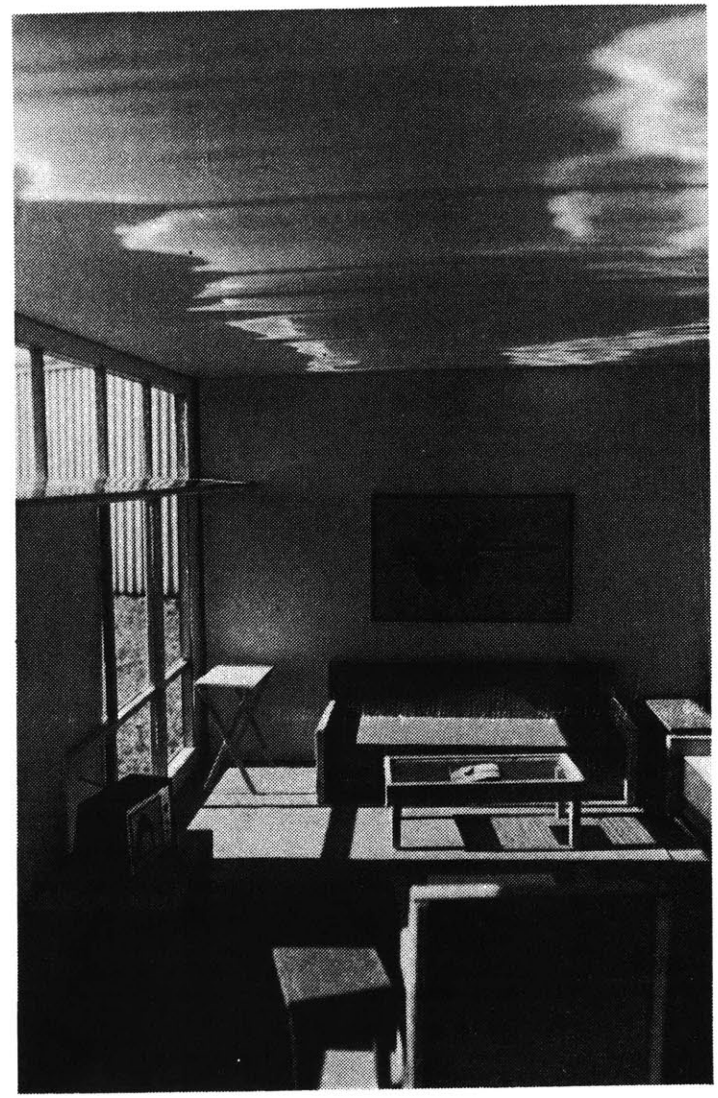
APPENDIX 4

DAYLIGHTING STUDIES

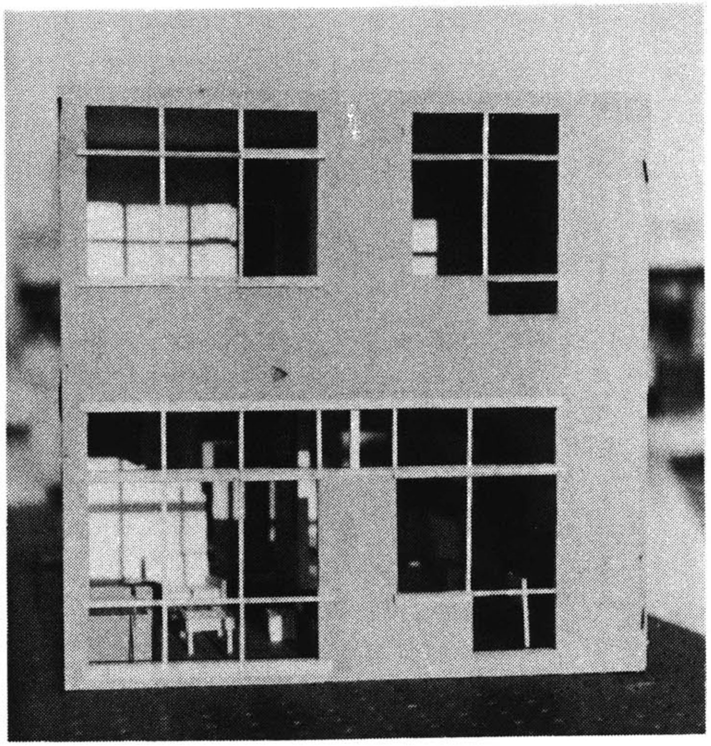
Natural Daylighting Appendix

The tremendous amount of south glazing in a passive solar design warrents the study of it luminous environment. Because sunlight has no scale or dimension, it is possible to test the daylight performance of a designed space with a model. For this purpose a lighting model is built of the typical three-bedroom, two-story unit.

This model is built @ 3/4" to 1'-0" scale to fascilitate qualitative observation, measuring and photographing of the daylit interiors. Kraft-backed fomecore is used for the model construction because of its opacity to light. Where white fomecore is desired, aluminum foil is applied over it to make it opaque. Unit furnishings and window mullions as well as wall and floor coverings with their appropriate reflectances ($\pm$10%) are modelled to accurately test the daylighting of the spaces. Additionally, the south window wall has sliding shutters and a removable light shelf to allow the testing of different window openings and light distribution configurations. Instead of glazing the windows, all the readings taken are multiplied by transmission factors.



PHOTOGRAPH OF LIGHT PENETRATION WITH THE LIGHT SHELF



THE DAYLIGHTING STUDY MODEL
(SOUTH ELEVATION)

Testing is done outdoors with the model properly oriented with respect to south. For this design, units face 16° west of south. Cloudy day as well as sunny day measurement are made with two light meters. Sky luminances are taken with a standard light meter held horizontally and shaded from direct sunlight. A remote reading light meter is used to measure the incident horizontal footcandles in the unit. The data from numerous measuring points help to determine the light distribution in each space.

Various combinations of window positions and the use of the light shelf are tested under sunny conditions. The model is also attached to a heliodon which tracts the sun's yearly path. This allows the study of light distribution at different times of the year. It is important to remember that when the model is tilted out of its horizontal position, some diffust lighting from the sky vault is lost. However, this loss does not alter the light readings enough to invalidate them.

From the overcast day data, daylight factors are calculated for each room. The daylight factor is defined as the ratio of the interior illumination to the unobstructed overcast sky luminance and is expressed as a percentage.

$$\text{Daylight factor} = \frac{\text{interior illumination}}{\text{unobstructed overcast sky luminance}}$$

These daylight factors are evaluated by the recommended values given by Lynes in Principles of Natural Lighting p. 186.

Living Rooms	not less than 1% over 1/2 the room depth from the windows.
Bedrooms	not less than .5% over 1/2 the room depth from the windows.
Kitchens	not less than 2% over 50% of the floor area

Results

On both sunny and cloudy days the experimental results indicate that the unit will appear to be well lighted. This merely substantiates the general qualitative evaluation of the spaces.

The use of high windows is essential for maximum light penetration. High windows light the ceiling which then becomes a large light source. The light shelf throws light onto the ceiling even deeper in the space and balances out the distribution. The darkest area of unit may be brightened by skylight or a clerestory over the closet in the small south bedroom.

Appendix 4a

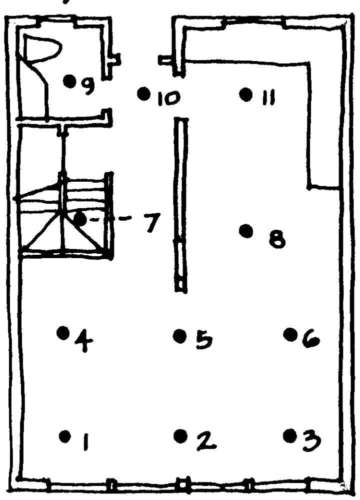
DAYLIGHTING MODEL STUDY- Daylight Measurements

Date: January 27, 1981
Time: 1:30 p.m.
Weather: sunny
Sky Luminance: 2750 fc
800 (shaded)

Test Conditions:
All the top windows in the living room opened. with the light shelf

low windows used in the bedrooms

Key Plans



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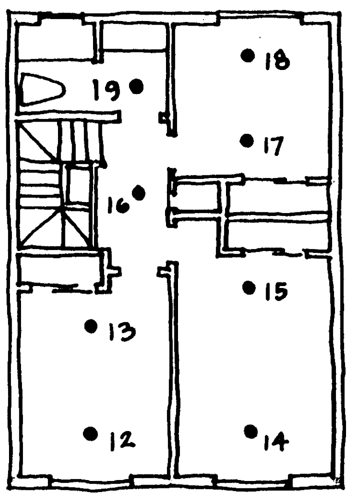

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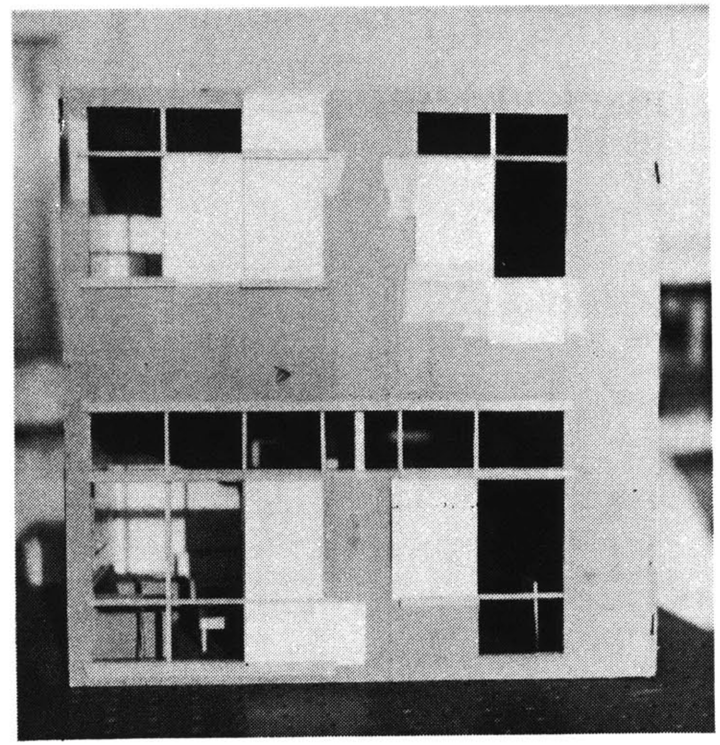
Data

location	meter reading (fc)	trans. reduction	daylight factor %	lighting level (fc)
1	2500	.72	65.4	1800
2	525	.72	13.7	378
3	2250		58.9	1620
4	1500		39.3	1080
5	1500		39.3	1080
6	2250		58.9	1620
7	285		7.5	205.2
8	300		7.8	216
9	115	.70	2.9	80.5
10	255	.72	6.7	183.6
11	350	.70	8.9	245
12	2000	.72	52.3	1440
13	280	.72	7.3	201.6
14	1525	.72	39.9	1098
15	230	.72	6.0	165.6
16	100	.61	2.5	70
17	145	.70	3.7	101.5
18	175	.70	4.5	122.5
19	140	.70	3.7	101.5

Appendix 4b



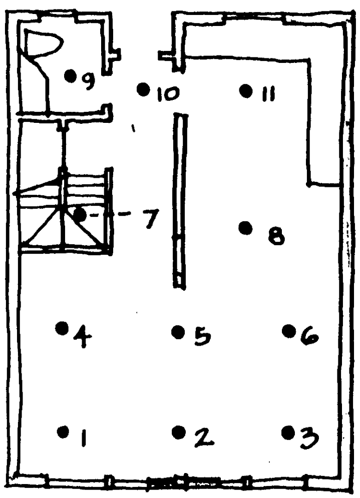
Appendix 4b

DAYLIGHTING MODEL STUDY- Daylight Measurements

Date: January 27, 1981
Time: 3:15 p.m.
Weather: sunny
Sky Luminance: 1200 fc.
425 (shaded)

Test Conditions:
Corner windows are emphasized in this test (see model photo). The central part of the room is solid wall

Key Plans



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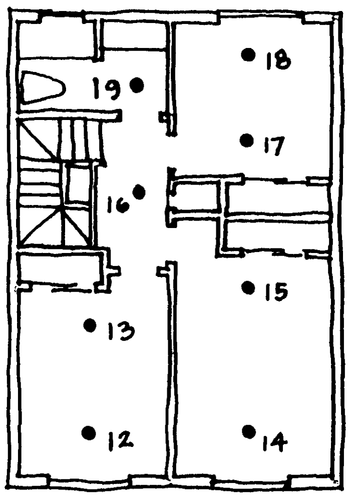

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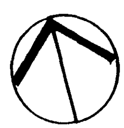
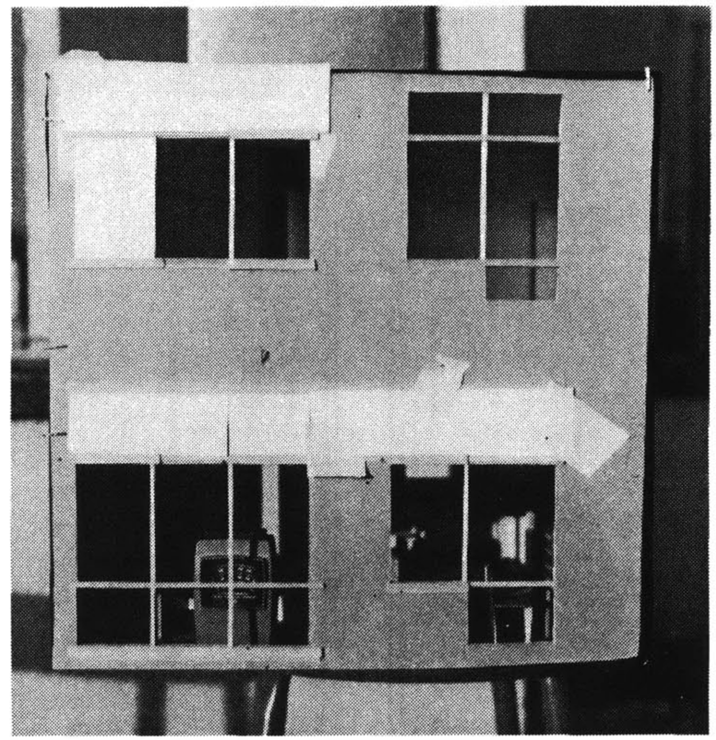


Data

location	meter reading (fc)	trans. reduction	daylight factor %	lighting level (fc)
1	950	.72	57	684
2	210	.72	12.5	151.2
3	900		54	648
4	175		10.6	127
5	225		13.5	162
6	200		12	144
7	125		7.5	90
8	900		54	648
9	75	.70	4.4	52.5
10	110	.72	6.6	79.2
11	150	.70	8.8	105
12	700	.72	42	504
13	225	.72	13.5	162
14	750	.72	45	540
15	170	.72	10.2	122.4
16	85	.61	4.3	51.9
17	70	.70	4.1	49
18	90	.70	5.2	63
19	30	.70	1.75	21

Appendix 4c



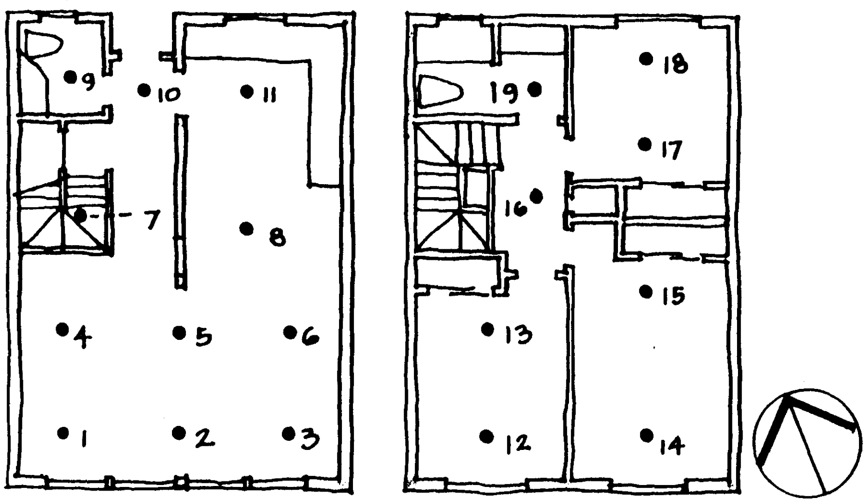
Appendix 4c

DAYLIGHTING MODEL STUDY - Daylight Measurements

Date: January 27, 1981
Time: 3:40 p.m.
Weather: sunny
Sky Luminance: 780 fc
400 (shaded)

Test Conditions:
emphasis is on the lower windows in the living room where no clerestory windows are employed. Only the living room is tested. Light shelf receives no light.

Key Plans

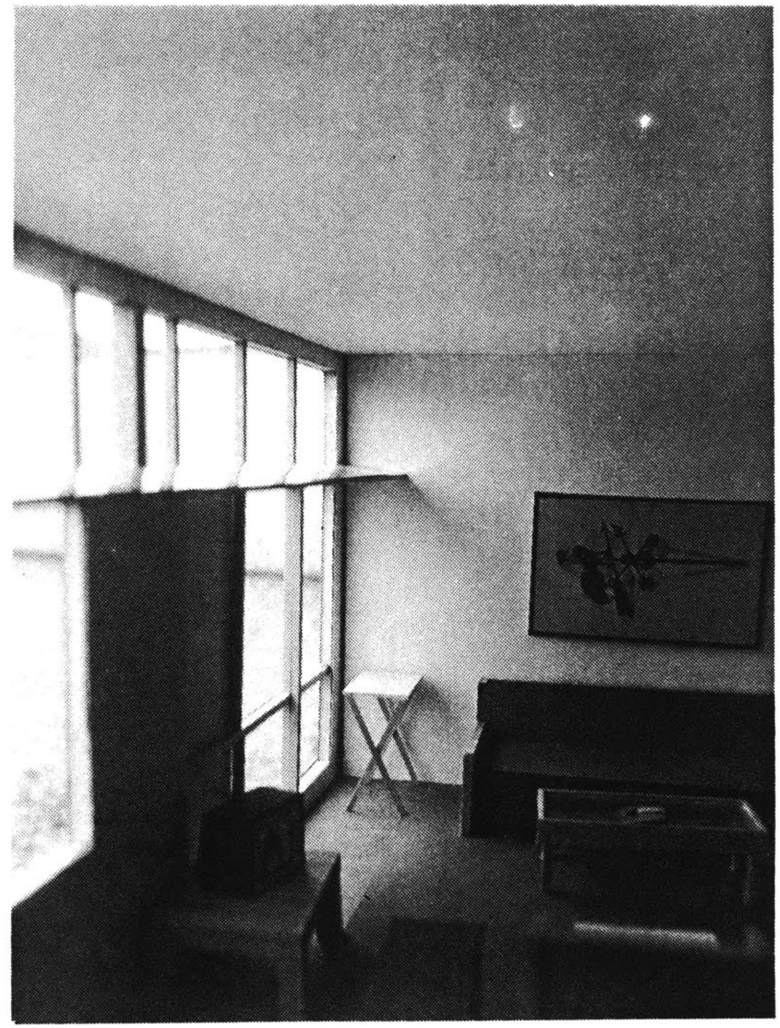


2
3

Data

location	meter reading (fc)	trans. reduction	daylight factor %	lighting level (fc)
1	600	.72	55.3	432
2	350	.72	32	252
3	500	↓	46	360
4	80	↓	7	57.6
5	140	↓	12.8	100.8
6	375	↓	35	270.
7	90	↓	8.3	64.8
8	110	↓	10	79.2
9	50	.70	4.6	36.
10	70	.72	6.5	50.4
11	75	.70	6.9	54
12	—			
13	—			
14	—			
15	—			
16	—			
17	—			
18	—			
19	—			

Appendix 4d



DAYLIGHTING MODEL
under cloudy conditions

Appendix 4d

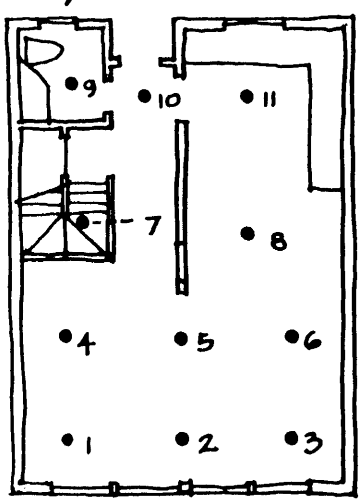
DAYLIGHTING MODEL STUDY- Daylight Measurements

Date: January 23, 1981
Time: 3p.m.
Weather: cloudy
Sky Luminance: 375 fc

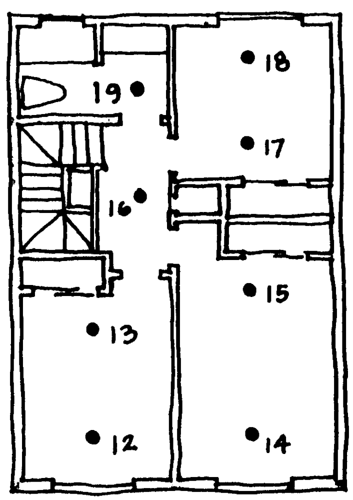
Test Conditions:
light shelf is used with the top windows. on 2nd floor

no high windows are used in the bedrooms

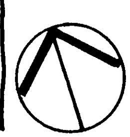
Key Plans



2



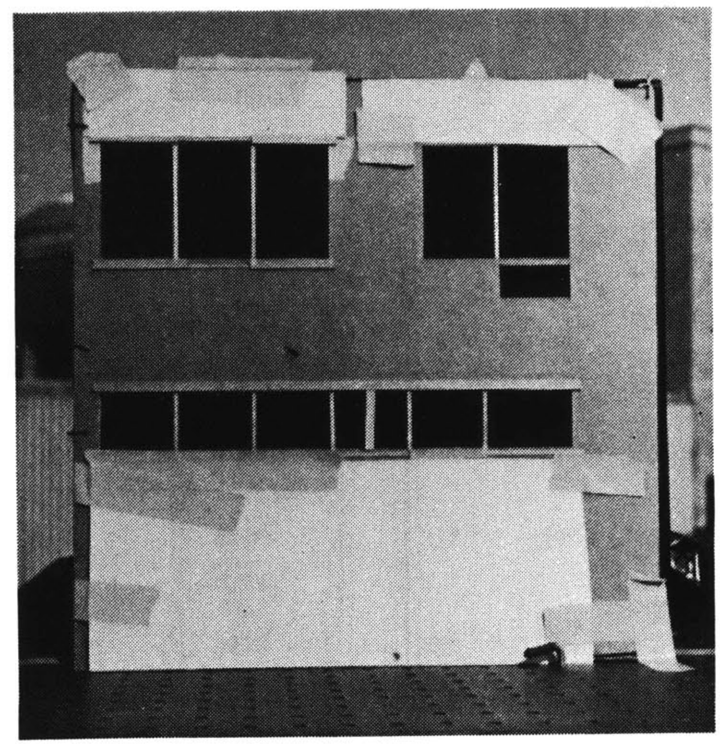
3



Data

location	meter reading (fc)	trans. reduction	daylight factor %	lighting level (fc)
1	150	.72	26.0	108
2	105	.72	20.0	75.6
3	135		19	97.2
4	55		11	39.6
5	73		14	52.6
6	50		9.6	36
7	20		3.8	14.4
8	85		16	61.2
9	10	.70	1.9	7
10	25	.72	4.8	18
11	55	.70	10.3	38.5
12	100	.72	24	90
13	90	.72	17	64.8
14	200	.72	26	97.2
15	90	.72	11.5	43.2
16	15	.61	2	7.5
17	18	.70	3.4	12.6
18	28	.70	4	19.6
19	7	.70	1.3	4.8

Appendices 4e and 4f

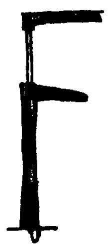


Appendix 4e

DAYLIGHTING MODEL STUDY- Daylight Measurements

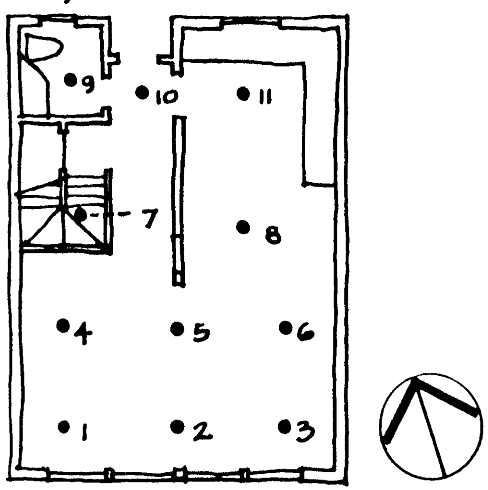
Date: January 30, 1981
Time: 11:15 a.m.
Weather: sunny
Sky Luminance: 3250 fc

Test Conditions:



Top windows used in conjunction with the light shelf to check the effectiveness of the light shelf

Key Plans



2

Data

location	meter reading (fc)	trans. reduction	daylight factor %	lighting level (fc)
1	425	.72	9.4	306
2	250	.72	5.5	180
3	190	.72	4.2	136.8
4	375	.72	8.3	270
5	275	.72	6.1	199
6	230	.72	5.1	165.6
7	210	.72	4.6	151.2
8	160	.72	3.4	115.2
9	130	.72	2.9	93.6
10	160	.70	3.4	112
11	140	.70	3.0	98

Appendix 4f

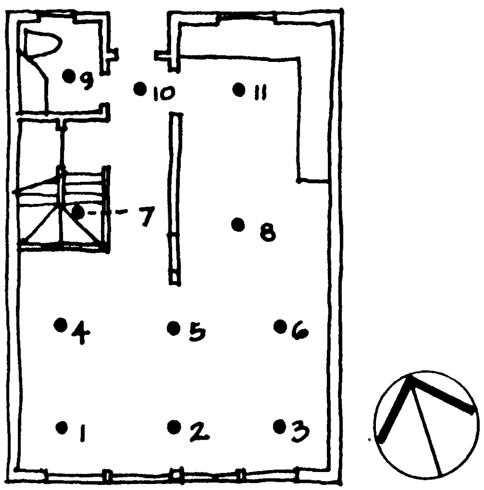
DAYLIGHTING MODEL STUDY- Daylight Measurements

Date: January 30, 1981
Time: 11:15 a.m.
Weather: sunny
Sky Luminance: 3250 fc

Test Conditions:

Top windows - no light shelf

Key Plans



2

Data

location	meter reading (fc)	trans. reduction	daylight factor %	lighting level (fc)
1	500	.72	11.0	360
2	290	.72	6.4	208.8
3	200	.72	4.4	144
4	225	.72	4.98	162
5	225	.72	4.98	162
6	195	.72	4.3	140.4
7	170	.72	3.8	122.4
8	140	.72	3.1	100.8
9	110	.72	2.4	79.2
10	135	.72	2.9	94.5
11	135	.70	2.9	94.5

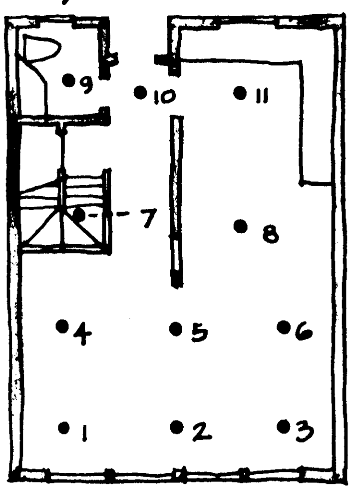
Appendix 4g

DAYLIGHTING MODEL STUDY- Daylight Measurements

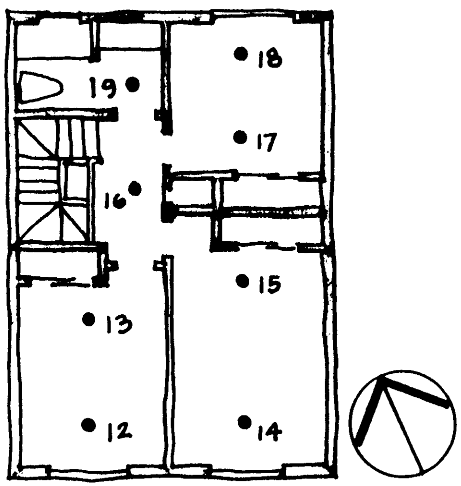
Date: Simulated Summer June 21 - July 21
Time: 1 pm
Weather: sunny
Sky Luminance: 4000 f.c.

Test Conditions:
simulated summer conditions for June 21st and July 21st at 1p.m. with canvas awning to shade light shelf.
Note: There is some reduction in lighting levels from the reduced sky vault exposure when model is tilted.

Key Plans



2



3

Data

location	meter reading (fc)	trans. reduction	daylight factor %	lighting level (fc)
1	3750	.72	67.5	2700
2	710	.72	12.8	511.2
3	3750		67.5	2700
4	833		15.0	600
5	755		13.6	544
6	500		9.0	360
7	300		5.4	216
8	275		4.9	198
9	100		1.8	72
10	210	.70	3.7	147
11	245	.72	4.4	176.4
12	2750	.70	48.0	1925
13	210	.72	3.8	151.2
14	3100	.72	55.8	2232
15	250	.72	4.5	180
16	100	.61	1.5	61
17	225	.70	3.9	157.5
18	155	.70	2.7	108.5
19	50	.70	.9	35

APPENDIX 5

COST COMPARISON OF AUXILIARY HEATING SYSTEMS

Appendix 5

COST COMPARISONS OF AUXILIARY HEATING SYSTEMS

The following calculations are based on the annual auxiliary energy requirement for the Solar Heated/ Energy Conscious Unit.

Annual Auxiliary Energy Use $= .675 \times 10^7$ BTU

Each auxiliary heating system is evaluated on its initial and operating costs. These are defined below:

Initial Costs - All expenses or costs incurred that are above the standard unit installation with a \$2,012 gas furnace.

Operating Cost - The cost of the energy needed to meet the aforementioned yearly auxilrary energy need. ($.675 \times 10^7$ BTU)

(1) Gas-fired Warm Air System

Initial Costs

50,000 BTUH Upflow Furnace (No Branch Ductwork) $\boxed{\$1,500}$

Operating Costs

Gas is 60¢/therm

$1 \text{ therm} = 1 \times 10^7 \text{ BTU}$

Auxiliary Energy Use in therms:

$$\frac{.675 \times 10^7 \text{ BTU}}{1 \times 10^5 \text{ BTU}} = 67.5 \text{ therms}$$

$$60¢/\text{therm} \times 67.5 \text{ therms} = \boxed{\$40.50}$$

Appendix 5

COST COMPARISON OF AUXILIARY HEATING SYSTEMS

② Radiant Heating System

Initial Costs

Thermal Storage Bags - $1.80/ft²
Electric Radiant Mats - $2.30/ft²

- Square feet of Bags:

  South-facing BR - 131.25 ft²
  " BR - 109.25
  Living Room - 280.0
  520.5 ft²

  520.5 ft² × $1.80/ft² = $936.90

- Area of Mats follows rule of thumb - ⅓ heated floor area - or 375 ft²:

  375 ft² × $2.30 = $856.66

- Installation: 5¢/ft² for mats

  375 ft² × 5¢/ft² = $ 18.60

- Wiring: $ 140.00

  $\boxed{\$\,1{,}954.16}$

*if mylarized louvers are used for light direction add $162.00 for 18' of louvers in the clerestory.

Operating Costs

- All electric rate = 6¢/kwh

A modified heating load is calculated because a lowered thermostat setting can be used for a radiant heating system. Because radiant heating heats people and furnishings directly, it feels warmer than a warm air system. So, the thermostat is set 6°F lower

$$\text{New BP} = 59°F - \left(\frac{2916.7\ \text{BTU/hr}}{256.35\ \text{BTU/hr/°F}}\right)$$
$$= 59°F - 11.47°F = 47.66°F$$

Degree Days for 47.66°F = 1990 DD
Seasonal Heating Load = UA × DD × 24
$(256.35)(1990)(24) = 1.13 \times 10^7$ BTU/yr

- Auxiliary Heating Use:

  1.13×10^7 BTU/yr $- .885 \times 10^7$ BTU/yr (solar gain) =
  $.339 \times 10^7$ BTU = 993.26 kwh
  993.26 kwh × 6¢/kwh = $\boxed{\$\,59.60}$

COST COMPARISON OF AUXILIARY HEATING SYSTEMS - continued

③ Oil Burning Furnace

Initial Costs

oil burning furnace is less than a gas-fired furnace

Operating Costs

Oil (for home heating) is \$1.10/gallon
(The most commonly used in domestic burners is Grade No. 2)

1 gallon No. 2 Grade Fuel Oil = 141,800 - 137,000 BTUs
avg. = 139,400 BTU/gal.

$$\frac{.675 \times 10^7 \text{ BTU}}{139,400 \text{ BTU}} = 48.4 \text{ gallons of oil}$$

48.4 gallons × \$1.10/gal = $\boxed{\$53.26}$

Annual Fuel Bill

④ Heat Pump

Initial Costs

packaged unit is \$1,500 and 3-4 are required to cover the 3-4 heated zones in the dwelling

3 × \$1500 = $\boxed{\$4,500}$

Operating Costs

Estimated to be \$10/year or so because the electricity use is quite low.

COST COMPARISON OF AUXILIARY HEATING SYSTEMS – Continued

• Analysis of Radiant Heating Back-Up system with no Thermal Storage Bags vs. Gas-fired Warm Air Auxiliary Heating System

RADIANT HEATING SYSTEM		GAS-FIRED FURNACE SYSTEM	
Initial Costs:			
Wiring	$140	Gas-fired Furnace	$1500
Radiant Heating Mats	$858.66		
	$998.66		$1,500
COST DIFFERENCE:		$501.34 less for radiant heating	
Operating Costs:			
Yearly Energy Use	$59.60	Yearly Fuel Cost	$40.50
COST DIFFERENCE:		$19.10 less for gas-fired system	

* The radiant heating mats without storage bags is most economical if electric costs remain low.

• HUD MPS Heating Load Calculations

According to HUD MPS an energy efficient multi-family low rise dwelling should have a load of less than 6.7 BTU/DD-ft²

The Solar Heated/Energy Conscious Unit designed has a load of:

$$UA = 256.35 \text{ BTU/hr/}^\circ\text{F}$$

$$\frac{\text{Load}}{\text{DD-ft}^2} = \frac{(256.35 \text{ BTU/hr/}^\circ\text{F})(24 \text{ hr/day})}{1120 \text{ ft}^2}$$

$$= \boxed{5.49 \text{ BTU/DD-ft}^2}$$

This falls well within the HUD MPS guidelines.

APPENDIX 6

SOLAR BUDGET CALCULATIONS

Appendix 6

SOLAR BUDGET CALCULATIONS

Additional Costs of the Solar System

- Added fixed double glazing:
  114.45 ft^2 x \$9.00/ft^2 = \$1030.05
- Heat Mirror (North-facing glass:
  74.8 ft^2 x 1.30/ft^2 = 97.24
- Concrete Block Party Walls (cost shared by two units):
  $\frac{1092\ ft^2 \text{ of wall} \times 25¢/ft^2}{2 \text{ units}}$ = 136.50
- Added roof insulation:
  From 3½" to 6" Batt is a 9¢/ft^2 increase,
  560 ft^2 x 9¢/ft^2 = 50.40
  Rigid Styrofoam Insulation
  560 ft^2 x 30¢/ft^2 = 168.00
- Canvas Awning = 150.00

TOTAL \$1,632.19

Cost Saving Tradeoffs

- Ductwork and Registers eliminated by the natural convection distribution \$127.54
- Rigid Styrofoam substituted for plywood sheathing

Standard Unit					
704.25 ft^2	x	60 ft^2	=	\$422.55	
Solar Unit					
− 484.05 ft^2	x	30 ft^2	=	145.00	
				\$277.55	
					277.55
TOTAL					\$405.09

ADDITIONAL INITIAL COST:

\$1,632.19	added cost of system
405.09	savings
\$1,227.10	EXTRA = 99¢/ft^2

With the heating savings of \$166.50 per year the payback period is:

$$\frac{\$1{,}227.10}{\$166.50} = \boxed{7.36 \text{ years}}$$

END NOTES

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3. Karen Buglass, Rental Payment by Neighborhood, City of Boston.

4. Office of Technology Assessment, Residential Energy Conservation, p. 77-78.

5. Office of Technology Assessment, op. cit., p. 78.

6. Office of Technology Assessment, op. cit., p. 30.

7. Styrofoam Brand Insulation, The Proven Answer For Home Insulation, p. 4.

8. William M. C. Lam, "Daylighting, Direction, Not Rejection."

9. Jim Leckie, et. al, Other Homes and Garbage, p. 145.

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